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WITH

A SUPPLEMENT

ON

THE DANGER ATTENDING THE PRESENT SYSTEM OF RAILWAY AND MARINE COLOURED SIGNALS.

BY

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TO THE

PRESIDENT, COUNCIL, AND FELLOWS

OF

THE ROYAL SCOTTISH SOCIETY OF ARTS,

WHOSE ENCOURAGEMENT OF THESE RESEARCHES

LED TO THEIR COMPLETION AND PUBLICATION,

THIS WORK

IS GRATEFULLY DEDICATED

BY THE

AUTHOR.

PREFACE.

Two years nearly have elapsed since the first portion of this work was communicated to the *Edinburgh Monthly Journal of Medical Science* for November 1853, with the title, "On the prevalence of Chromato-pseudopsis, or Colour-Blindness." The subject was one but remotely connected with my customary studies, and I did not originally intend to do more than write two or three papers upon it. As examples of Colour-Blindness, however, multiplied on my hands, and the theoretical and practical importance of many of the questions connected with its occurrence became more apparent, I was led to study it more deeply, and to write upon it at greater length. The results of this study are contained in greater part in this volume, which is to be regarded, however, only as a very imperfect contribution to the history of a remarkable and by no means rare peculiarity of vision. It requires for its full elucidation a profounder acquaintance with Optics, Anatomy, and Physiology, than I dare pretend to; and what I could do towards its investigation could not be done continuously, but only at irregular and often far-separated intervals, in such periods as could be saved from the time imperatively demanded by professional duties.

With all its imperfections, this work will, I trust, create or deepen the conviction, that the study of Colour-Blindness will throw light upon intricate de-

partments of Scientific Optics, Anatomy, and Physiology; and that already it has an important practical bearing on those Æsthetic Arts which express Beauty by Colour; and on those Economic Arts, such as Mapping, but especially Signalling, which employ Colour graphically.

The work is constituted as follows:—From page 5 to 125, it is simply a reprint from the *Edinburgh Monthly Journal of Medical Science* of the papers which appeared in ten numbers of that periodical, under the general title "On the prevalence of Chromato-pseudopsis, or Colour-Blindness." With the exception of a very few insignificant verbal corrections, those pages (which indeed are printed from the types as they were set up for the *Journal*) have not been altered except in the numbers marking the paging. The pages of the reprint correspond to those of the *Edinburgh Monthly Medical Journal* as follows:—

Reprint.	Journal.
1 to 24	377 to 396, November 1853.
25 – 40	491 – 507, December —
40 – 48	37 – 44, January 1854.
48 – 62	309 – 323, April —
62 – 67	411 – 416, May —
68 – 77	1 – 10, July —
77 – 87	97 – 107, August —
88 – 101	226 – 240, September —
101 – 111	393 – 403, November —
111 – 125	490 – 504, December —

As the *Medical Journal* was not open to the discussion of questions in Speculative Optics, or of such practical relations of Colour-Blindness as are only remotely related to Medicine, those subjects are but slightly referred to in the reprint. I have accordingly added to it a Supplement and Appendix, in which certain of these are considered. The most important practical relation of Colour-Blindness is that which it has to Railway and Ship Signals. To this the Sup-

plement (pages 127–152) is devoted. It is a reprint from the *Transactions for* 1854–1855 *of the Royal Scottish Society of Arts*, to which it was read last January; and as it was intended to contain a sufficiently full discussion of Colour-Blindness to enable practical men, without consulting other works on the subject, to understand its relations to our systems of Signals, it goes in some degree over the same ground as that traversed by the text of this work. This it does, however, to but a small extent, and it is chiefly occupied with new matter. I owe it to the Scottish Society of Arts to state here, that it has not only permitted me to use this reprint, and has circulated it at its own expense among the Railway Companies, but, whilst prosecuting these researches, it has unsolicitedly placed at my disposal a grant of money to be expended on the inquiry. The whole of this work in truth, and not merely the Supplement, is largely due to the encouragement afforded by the Society of Arts, to which the greater part of its contents was orally communicated before publication.

The Supplement is followed by a valuable paper "On the Theory of Colours in relation to Colour-Blindness," communicated at my request by Mr James Clerk Maxwell, to which I need not allude further here, as repeated reference will be found to it in the Supplement and Appendix.

In the Appendix I have endeavoured to compensate in some degree for the imperfections inseparable from a work, the first part of which was printed some twenty-two months before the last was written. My views on Colour-Blindness have been greatly enlarged, and in some respects altered, during that interval; and were the whole work now to be re-written, I should make considerable changes upon it. But as that can-

not be in the meanwhile, I have indicated, in the Notes constituting the Appendix, what the topics are on which the earlier statements in the volume most demand qualification; and as these are specially connected by the references in the table of contents, with the pages of the text to which they refer, it will not be difficult for the reader to consider them together.

I will also mention that the inquiry into the "Relation of the Colour of the Choroid to Colour-Vision," which occupies pages 88–104 of this volume, and partakes in great part of the character of an Excursus or Episode, is treated in several respects more fully in a paper read to the Royal Society of Edinburgh last April, and entitled "On the Extent to which the Received Theory of Vision requires us to regard the Eye as a Camera Obscura." It is printed in *Trans. R. S. E.*, Vol. xxi., Part ii., p. 327.

I have many parties to thank for assistance in prosecuting these researches. Professor Kelland most kindly aided me in the strictly optical portions of my inquiry. Mr William Swan rendered me a similar service, and so did Dr Thomas Wright; and latterly I profited largely, as the Supplement and Appendix will sufficiently show, by the interchange of opinions with Mr James Clerk Maxwell.

For the knowledge of accessible cases of Colour-Blindness I am indebted to Mr Walker, Dr John Struthers, Dr James Sidey, Dr David Skae, Dr Stark, Dr Halliday Douglas, Professor John Hughes Bennett, and several other medical men in Edinburgh; and the Editor of the Athenæum did me a signal service by publishing a request for undescribed cases, which led to many being communicated to me from a distance. To Mr Walker and Dr Struthers I am also indebted, as well as to Dr Sanders, Dr Cobbold, and Professor

Goodsir, for information and guidance on questions connected with the anatomy and physiology of the eye. I am under similar obligations to Mr White Cooper of London, and to none more than to Dr W. Mackenzie of Glasgow. In connection with this experienced oculist's name, I take the opportunity of noticing that a statement of the extreme rarity with which the subjects of Colour-Blindness apply for advice to eye-surgeons regarding it, is greatly lessened in force by a misprint (p. 79) of 4000 for 40,000. Among forty thousand cases of eye-disease treated by him in thirty years, Dr Mackenzie recalls only two of Colour-Blindness.

In the tedious labour of collecting the statistics of Colour-Blindness, I received the most willing and efficient aid from my former colleague in the Edinburgh Veterinary College, Mr Finlay Dun; and our labour was greatly lessened by the courtesy of the officers in command of the 4th Infantry, the 7th Hussars, and the Artillery in Leith Fort, at the period when the vision of these soldiers was tested by us.

For a knowledge of the methods of signalling at present in use on railways, I am chiefly indebted to the good services of Mr Henry Lees, the experienced Secretary of the Edinburgh, Perth, and Dundee Railway. I received valuable information also from Graham Hutchison, Esq., one of the Directors of the Great Northern Railway; and I owe it to the various railway officers I have consulted to state that I have uniformly found them most willing to give me information, and to assist my inquiries.

I cannot, as they prefer to remain anonymous, thank by name the large number of Colour-Blind persons who communicated their cases to me, and permitted me to publish them. I have already expressed in private, to the majority of these parties, my obligation to them;

and I now repeat that acknowledgment publicly, including in its objects those whom I have not been able otherwise to thank.

To one class of my unnamed correspondents I have a special reference to make. I have alluded, at page 35, to the circumstance, that a considerable number of the cases of Colour-Blindness which I have recorded, occurred among members of the Society of Friends, and have implied an intention of attempting to show that this was probably not accidental. This intention I have not fulfilled in the sequel, in consequence of the statements made to me on the subject conflicting greatly with each other. I thought it not unlikely that the systematic avoidance of gay colours in dress, furniture, and the like, which from laudably conscientious motives is practised by Friends, would develop and render hereditary in their families an indifference to colour, which in the later generations might appear as true Colour-Blindness. On asking, however, the opinion of a few members of the Society of Friends on this hypothesis, they have replied that none were fonder of gardens than they, or delighted more in the hues of flowers, or in the colours of Nature in general; and in a word, that they were not as a body indifferent to colour.

This reply carries much weight with it, and the known success of members of the Society in question as manufacturers of dyed goods, and their practical skill as judges of colours, certainly show that Friends may be as free from Colour-Blindness as others. In further proof of the same fact (if it needed further proof), the painter Benjamin West, and the engraver William Miller, might be referred to as artists whose nice appreciation of colour is familiar to lovers of the fine arts; whilst, if Dalton be a striking

example of a Quaker philosopher who mistook colours, Thomas Young is a not less striking example of a Quaker philosopher who excelled in distinguishing them, and has largely contributed to our knowledge of the Theory of Colour.

Notwithstanding all this, however, the effect upon the great majority of Friends, of being surrounded from early infancy by neutral, subdued, or sombre tints, cannot be favourable to the development of an acute sense of colour, especially in the case of those of them (including most, probably, of the male sex) whose professions do not lead them to be conversant with colours, and who do not, by the cultivation of flowers or otherwise, make amends to themselves for the systematic repression of the natural relish for brilliant and diversified colours which they practise. Such is probably the case with the majority of the less accomplished male Friends in the larger cities; and the century and a half or two centuries which have elapsed since the forefathers of the present generation of Quakers adopted Quakerism, is sufficient to have permanently affected the Colour-Vision of not a few of their existing representatives.

This conclusion is in harmony with the considerable number of cases of Colour-Blindness which have occurred among Friends; yet the cases are too few to make it safe to generalize from them. I am content, therefore, for the present to draw attention to what may be only a coincidence, in the hope that such intelligent Friends as may read this statement will inquire into the matter, and acquaint me with the result.

Elm Cottage, Edinburgh,
1*st September* 1855.

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ON THE PREVALENCE OF CHROMATO-PSEUDOPSIS OR COLOUR-BLINDNESS.

The co-existence of perfect vision in other respects with an inability, more or less complete, to distinguish colours from each other, has within the last few years attracted considerable attention. Some very distinguished men, such as Dugald Stewart, M. Sismondi, and John Dalton, have been the subjects of this peculiarity of sight, and the last named, by reporting his own case, has earned at the hands of the Continental philosophers the unwelcome distinction of giving his name to the peculiarity in question. It has been called Daltonism, and its subjects Daltonians. The countrymen of Dalton have protested against the immortalising of his name, in connection with a personal defect; and the chemists of all countries might claim that the term Daltonian is needed by them to distinguish those who adopt the famous opinions of Dalton, concerning the atomic constitution of matter. Other terms, accordingly, have been devised for this affection of vision, chiefly of Greek origin, such as *chromato-pseudopsis*, *dyschromatopsis*, *dyschrosis*, *parachromatism*, and the like; none of which are very euphonious, whilst most of them are far from explicit. The term *chromato-pseudopsis*, i.e., *false vision of colours*, has, upon the whole, been preferred by scientific men, and it very fairly represents the general character of the affection under notice, which more frequently shows itself as an abnormal perception of colours, than as a total inability to discern them. Yet there are cases on record (and I shall have to report one myself, occurring, too, in the person of a house-painter) where the perception of black and white, *i.e.*, of degrees of illumination, was all that existed to represent the sense of colour, so that such a person might be justly said to be *blind to colours*. And in all the subjects of chromato-pseudopsis, there exists either inability to discern a single colour, such as red; or inability to discern the difference between two colours, such as green and red; so that they may be said, with sufficient propriety, to be blind to red, or blind to the difference between

green and red, *i.e.*, more explicitly, blind to one of two colours presented simultaneously to the eye. It seems, therefore, that the term Colour-Blindness, introduced by Sir David Brewster, may be fully justified as a scientific term; and even if it were less defensible than it is, its employment would be warranted by the necessity which exists for some expressive English name for an affection of vision which, from the evils entailed by it on its subjects and their neighbours, is an object of importance to the entire community. The English word, moreover, has the advantage over the Greek of permitting an adjective and noun to be readily formed from it, so that we can speak of those to whom it refers as colour-blind persons, or as *the* colour-blind; whereas the awkwardness of naming such parties *chromato-pseudopts* or *idiopts*, has been felt by all, and has doubtless been one of the chief causes why so objectionable a phrase as Daltonian has not long ago been discarded.[1]

The authors on colour-blindness have, many of them, been as famous as its subjects; but into the literature of the question it is not my intention to enter, as this has been ably and amply discussed by Professor Wartmann of Lausanne. A translation of his paper appeared in "Taylor's Scientific Memoirs" for 1846, accompanied by notes by the English editor. To this paper, and the works which are quoted in it, I refer those who wish to learn the present state of our knowledge concerning colour-blindness.

The object of the present communication is chiefly practical, and is mainly to direct the attention of the community, and especially of medical men, to the nature and prevalence of the affection under notice. In spite of the papers which have been published on the subject, the extent to which colour-blindness prevails has been so little credited, that more than one eye-surgeon of experience has never examined a case of it; yet, as will appear, cases abound in all ranks and professions throughout the country.

My own special attention was directed to the subject, from the blunders which I found my chemical pupils make, in reference to the colours of compounds. After making every allowance for imperfect exposition on my part, and insufficient attention on the part of my students, and after also making a large deduction from inaccurate answers, on the score of imperfect remembrance, and inability to name colours, I still found, both in the laboratory

[1] The word Daltonian appears to have been in use for fifty years in the Academy of Geneva, and to have been first employed in print in 1827, by Pierre Prevost (*Taylor's Scientific Memoirs*, 1846, *p.* 158). It was thus introduced into use during the lifetime of Dalton, whose case was published by himself in 1794 (*Mem. Lit. and Phil. Soc. Manchester, Vol. V.*). Whether he was aware of the use made of his name, I do not know, but he certainly would have acquitted the Genevese philosopher of any intention to mock him, by calling those who had the same peculiarity of vision as he possessed, Daltonians. In truth, Dalton seemed rather pleased than annoyed by his colour-blindness, and enjoyed the amusement which his mistakes regarding colours occasioned to others.

and lecture-room, that many a pupil was puzzled to describe the changes which occur when an acid or an alkali acts upon a vegetable colouring matter, although to a normal eye these changes are of the most marked character; and that in general I could count with little confidence upon accurate answers to questions regarding the colours of bodies. At intervals since studying Dalton's account of his colour-blindness, some years ago, the suspicion crossed my mind that some of my pupils must be colour-blind; but I set the notion aside as extravagant, till last winter, when the perplexities which an intelligent laboratory pupil constantly betrayed in deciding on the colours of precipitates, led me to investigate his case, and he soon proved to be a well-marked case of colour-blindness, as, indeed, he had not long before discovered for himself. Another well-marked case showed itself in the person of a middle-aged gentleman attending my lectures, who had become aware of his peculiarity of vision in boyhood. I had thus an opportunity, during several consecutive months, of examining two characteristic examples of colour-blindness, and as the subjects of it were educated intelligent men, who afforded me every facility for testing their sense of colour, I soon learned what were the points of most importance in examining such cases. I have since had the opportunity of examining many additional examples, which I shall report in full in the sequel; but I wish first to mention, that struck by the danger which attends the use of coloured signals on railways, if any of the signal-men are colour-blind, and satisfied from the published statistics of colour-blindness, that it must present itself in the army of railway servants spread over Europe and America, I brought this aspect of the subject before the Royal Scottish Society of Arts, and afterwards published a letter on it, in the Athenæum for April last. This letter contained a request for information regarding unpublished cases, which led to my receiving a number of interesting communications, the more important of which are embodied in what follows.

I bring the entire subject before my medical brethren, engaged in actual practice, as they have better opportunities than most other classes of the community, for ascertaining the extent to which colour-blindness prevails; an important point, on which our present information is exceedingly defective. It will presently appear, also, that apart from its interest in a scientific point of view to the physiologist and pathologist, there is no profession concerned with colour as a property of bodies, which has not an interest in lessening the severity and diminishing the frequency of colour-blindness.

I shall consider the subject under the following divisions:—

I. Nature of Chromato-Pseudopsis or Colour-Blindness.
II. Cases illustrative of the Degrees and Varieties of Colour-Blindness.
III. General Conclusions concerning the Colours perceived with

most difficulty, or most liable to be confounded with each other by the Colour-Blind.

IV. Extent to which Colour-Blindness prevails in Males and Females.

V. Theories of Colour-Blindness.

VI. Advantages and Disadvantages of Colour-Blindness; its Prevention and Cure.

I.—*Nature of Chromato-Pseudopsis or Colour-Blindness.*

Writing chiefly with a practical end in view, I shall be content to consider colour-blindness as it shows itself in eyes otherwise normal, as of three kinds.

1. Inability to discern any colour, properly so called, so that black and white, *i.e.*, light and shade, are the only variations of tint perceived.

2. Inability to discriminate between the nicer shades of the more composite colours, such as browns, greys, and neutral tints.

3. Inability to distinguish between the primary colours, red, blue, and yellow, or between these and the secondary and tertiary colours, such as green, purple, orange, and brown.

It is to this last variety of colour-blindness that I shall chiefly refer; but a little must first be said concerning the other two kinds. It will be convenient also, in considering the first and rarest form of colour-blindness, to refer to certain difficulties which attend the examination of all cases of this affection of vision. These difficulties can best be referred to, as they present themselves in those in whom the perception of colour is at zero.

Total colour-blindness is very rare, but several well-marked cases of it are on record,[1] and it is remarkable that insensibility to colours is not only compatible with distinct vision in other respects, but appears frequently to be attended by a perception of objects very faintly illuminated, such as those sensible to colours do not possess. Perhaps, however, this is only what we should expect; for a retina unfatigued by the impression of colour, will preserve a sensitiveness to faint light such as an ordinary eye, exhausted by the reception of tints of all kinds, cannot retain. In writing this, I do not wish to assert that perfect achromatism has certainly been found in any human organ of vision. None of the recorded cases of total colour-blindness have been examined physically with such care as to warrant us in saying that it was absolute. With the optical instruments now accessible to us, and especially with the means of producing the purest and most brilliant colours which the apparatus for polarising light secures, we should probably find no human eye otherwise perfect, absolutely insensitive to colour.

And even if it were altogether unimpressible by colour, it appears

[1] Taylor's Scientific Memoirs, 1846. Pp. 162, 163.

exceedingly doubtful whether we should be able to discover that it was. We have it not in our power to subject an eye simply to the influence of colour. Every luminous ray is (in the language of the Material Hypothesis of Light) a bundle of colour-giving, heat-giving, and chemical or actinic rays, mingled in unequal proportion. Each colour-ray, therefore, carries along with it to the retina, a different number of heat-rays and chemical rays. Thus, if for simplicity's sake, we assume only three colours to exist, red, blue, and yellow, then the red ray of the spectrum, which the painter metaphorically styles a warm colour, is in reality much hotter when tried by the thermometer, than the blue or yellow. The blue, which is the coldest and darkest of the three primary colours, greatly excels the red and yellow in the number of chemical rays which accompany it; whilst the yellow, which is totally destitute of such rays, and contains very few heat-rays, must necessarily consist almost entirely of colour-rays; and it further excels red and blue in luminosity. The retina, accordingly, in so far as it is influenced by heat, will be most affected by the red ray; in so far as it is susceptible of chemical change, by the blue ray; and in so far as it is influenced by luminosity, by the yellow ray; apart from the special impressions made upon it by each ray in virtue of its colour.

When, therefore, we ask any one to gaze at a rainbow (which I select as the great natural representation of many colours) and tell us what he sees in it, we ask him to report on a series of complex sensations, to the production of which the brightness, heat, colour, and chemical force, present in the light by which he sees it, all do, or at least may, contribute. Such a spectator, though absolutely blind to colours, might retain susceptibility to all the other influences of light, and would probably possess it in a higher degree than those who were not colour-blind. It is certain at least, as the sequel will show, that the colour-blind, of all degrees, often possess in perfection the power of distinguishing shades of the same colour; and that when they confound two colours, such as red and green, they assort together, with great nicety, the light and dark shades of the one with the similar shades of the other.

The most severe sufferer, accordingly, from colour-blindness, may be expected to see as large and as perfect a rainbow or spectrum as others do, although to him it is colourless. The different bands, such as the bright yellow, the dark blue, and the intermediate red, will affect his eye differently, in virtue of their different luminosity; and if he had been accustomed from early life to distinguish degrees of brightness by the terms yellow, red, and blue, we should never discover, by his description of the rainbow, that he was colour-blind at all.

It is true, that if difference in luminosity were all that distinguished one band of the rainbow from another in the eyes of the colour-blind, it should be possible to paint a spectrum in black and white, which would satisfy them as well as a coloured one; and in

that case we should have a certain proof that colour was, for them, non-existent. Probably, however, only a colour-blind artist could execute such a black and white spectrum as would satisfy a colour-blind eye, and it would appear very strange to normal eyes.

But, for the reasons already given, it seems certain that the unequal temperature and chemical energy of the several bands of the spectrum will be as acutely felt by colour-blind as by normal eyes, and therefore that no combination of light and shade would impress even an achromatic retina as a combination of colours does. A colour-blind person, therefore, would find something wanting in a black and white spectrum, and could never make us certain that that something was not colour.

What has been said of those who are totally colour-blind, applies in great part to those who are partially so; only investigations of the latter are much simplified by the fact, that in general they are cognisant of two of the primary colours, and are often also not altogether unconscious of the third. But all cases of colour-blindness agree in this, that to the extent of its occurrence in any one, it implies a condition of vision, in reference to which there is not a common experience, and therefore cannot be a common language between those conscious of colour and those unconscious of it. The information, accordingly, which they can convey to each other is almost solely of a negative kind. We cannot, for example, give to one who never saw green a positive conception of what we understand by it: we can at best make him aware that it is none of the colours he does see. And he, on his part, cannot make us understand what *positive* impression green makes upon his eye, although he may satisfy us that it is something different from that which blue or yellow makes.

It must therefore be remembered, that the report of every case of colour-blindness is rendered hopelessly imperfect, in a twofold way, viz., by the impossibility of subjecting the eye to the test of colour, unaccompanied by other agencies, and by the impossibility of procuring from the colour-blind a positive account of the peculiarities of their vision.

The cases of total colour-blindness collected by Wartmann have been imperfectly described by their original observers. One goes back to 1684, and is thus detailed:—"A young woman, 32 or 33 years old, came to consult Dr Dawbeney about her sight, which, though excellent in other respects, incapacitated her from appreciating any other colour than white and black, although she could often read for nearly a quarter of an hour in the greatest darkness." A family is referred to by Spurzheim, "all the members of which could only distinguish black and white." Three persons of one family, named Harris, are also referred to, "who distinguished in colours only tints of luminous intensity, calling all bright tints white, and all dull ones black."[1]

[1] The original authorities for these statements are given in Taylor's Scientific Memoirs, 1846. Pp. 162, 163.

I have not myself met with a case corresponding to those, although I shall have occasion, further on, to refer to a physician who confounds all colours. One, however, has been reported to me by Mr Charles Inglis, of 48, Hanover Street, Edinburgh, who was well acquainted with the party. He has recently gone to Australia, so that he is for the present beyond the reach of inquiry. According to his own testimony, and the belief of my informant, "he could not distinguish any colours but black and white;" yet, strange as it may seem, he was a house-painter. The explanation of his prosecuting a calling, for which apparently he was so unfitted, is found in the fact, that he was an excellent draughtsman, with a good eye for form, and skilful in designing. He trusted to his wife to keep him right in selecting and mixing colours; but on one occasion, when she was out of the way, and workmen were scarce, he took a part himself in painting a public building in England, which he had been employed to put in order. He mixed the colours himself, and believed that he had produced a stone-tint, with which he proceeded to cover the walls; but after he had gone over some square yards, he was informed that he was painting the building *blue!* I regret that I can supply no farther particulars concerning this interesting case.

2. The second variety of colour-blindness, where the nicer shades of the more composite colours alone are mistaken, is *apparently* the rule rather than the exception in the majority of persons, at least of the male sex, in this country. But the sense of colour is so little cultivated amongst them, that the power of discriminating between tints is often dormant rather than absent; and the excessively scanty nomenclature of colours with which they are in general satisfied, does not furnish the means of distinguishing between colours and their shades, although that distinction may be perfectly well perceived. Even educated men hesitate to pronounce between scarlet and crimson, and are often content to call both, throughout all their shades, *Red.* Among the less educated, the reluctance to name colours is still greater; and if difficulty in naming were accepted as implying difficulty in distinguishing colours, we should be compelled to infer that the true perception of these was a very rare gift. In examining, for example, one by one, the Chemical Class of the Edinburgh Veterinary College, amounting to some sixty persons, I found the great majority decline to give names to any colours but red, blue, yellow, green, and brown. Purple and orange they would not name, although they described the relation of these to red, blue, and yellow, with sufficient accuracy. Without a little circumspection, accordingly, one might easily be misled into the belief that colour-blindness is much more common than it really is. But names of colours can quite well be dispensed with in examining cases of this affection. A safer method is, to request that a number of differently coloured squares of cloth, or paper, or glass, or skeins of worsted, be arranged so that all of the same colour and shade are placed together. When

this is done, it will frequently be found, that those who make no mistake in matching full tints of the primary and secondary colours, err in certain of the fainter shades of both, and in all the shades of some of the more mixed colours. Thus the difference between pink and pale blue is a puzzle to many who do not otherwise confound colours. Mr Crombie, dyer, Brown Square, Edinburgh, informs me of three persons known to him, connected with dyeing, to whom the tints in question were a constant occasion of mistake. Messrs Grieve and Company, late of South Bridge, Edinburgh, had in their employment a person who could match all colours but drabs. Professor S. is never certain, even by daylight, of the difference between blue and green; and many persons confound pink with pale yellow. No distinction, however, of any value in a scientific point of view, can be drawn between such cases and those which are chiefly discussed in this paper, for the difference between them is plainly one only of degree; but it is practically convenient to separate them, for whilst the milder forms of true colour-blindness are as incurable as the more severe, they cannot always be distinguished, especially in the young, from an inability to discriminate certain colours, which education is quite competent to remove. In truth, we are all by birth colour-blind to some extent; and painters know how long it is before the most susceptible eye acquires its maximum sensibility to colour. It will be more convenient, however, to reserve the full consideration of what may be called curable colour-blindness for another part of the paper.

3. The third form of colour-blindness, in which red, blue, yellow, purple, orange, green, brown, etc., are respectively mistaken for other colours, or all confounded together, is the most important variety of this affection. In extreme cases, although colours are occasionally quite correctly named, there is no certainty as to any colour. In less severe cases, the majority of colours are seen accurately, but two at least (as red and green), and generally four (as red, green, olive, and brown), are not distinguished from each other. The examples adduced in the sequel will illustrate this and many other points, and I reserve the statement of those general conclusions which the present state of our knowledge on colour-blindness seems to warrant, till the cases in question have been considered. There are one or two points, however, which first require notice. Of the three primary colours, yellow is certainly that which gives least difficulty to those not absolutely unconscious of colour. The majority of the colour-blind see it perfectly, and no case, so far as I know, is on record where yellow was the colour most liable to be mistaken, or where it was confounded with its complementary purple. Blue, if pure and well illuminated, is readily recognised by the majority of those who are colour-blind, and a few describe it as the colour they see best. Yet, singularly enough, though blue and yellow are so well seen, their combination, green, is one of the great stumbling-blocks of those who confound colours. It is frequently

mistaken for blue, still more frequently for red, and occasionally for yellow.

Red is the primary colour most distracting to the subjects of colour-blindness. For some it has absolutely no existence, for many it is undistinguishable from its complementary green; and the most famous cases of colour-blindness, including that of Dalton, are connected with a confusion or identification of red with green. A rarer but not less interesting case, is the identification of red with black. Uncertainty as to red and green might be expected to imply a corresponding uncertainty in discriminating the more complex colours into which they enter, and to a great extent this is the case. Purple is confounded with blue, the red apparently not being visible. Orange is called yellow. Olive is confounded with brown or rather russet, the green in the one, and the red in the other, inducing the same confusion as they do when seen together in a state of purity.

The following cases, which have come under my notice during the last nine months, are, with one exception, published now for the first time. Several I have had the opportunity of examining myself. Several have been examined by others, who have reported them to me. Others rest upon the authority of the parties themselves who communicated them. The names of the parties have, at their own request, been omitted in the majority of cases; but as it is desirable, for the sake of statistics, to guard against the same case being described by two observers, and counting as two cases, I have placed a list of the names in the hands of the Editor of the "Monthly Medical Journal," so that those who encounter cases of colour-blindness may learn from him, or from me, whether they are described in this paper.

The letter of the alphabet, marking each case, is the ultimate, not the initial, letter of the party's name. I have been driven to this departure from the ordinary practice by the somewhat singular circumstance, that one alphabetical letter largely predominates in the surname-initials of my cases; so that on grounds as good as those on which statistical conclusions are often based, I might affirm, that persons whose surnames commence with a particular letter of the alphabet, are more liable than others to colour-blindness.[1]

[1] Some have thought that colour-blindness was accompanied by a peculiar colour of the iris; others by a peculiar appearance of the pupil; others by a peculiar expression of the eye; others by a prominence in the middle of the superciliary ridge (the phrenological organ of colour). Had the advocates of the importance of any one of those physical characters, as an index of colour-blindness, encountered as many examples of its occurrence, as I have encountered of a common initial in the surnames of the subjects of that peculiarity of vision, they would probably have considered their view as established; and yet these cases might be quite exceptional, and prove to be unimportant as soon as the investigation included a larger number of persons. It may illustrate the danger of induction from too few particulars to mention, that the obnoxious initial marked the surname of the *first* colour-blind person I encountered; that it characterises the four severest cases which have come before me; that it occurs in

II.—*Cases Illustrative of the Degrees and Varieties of Chromato-Pseudopsis, or Colour-Blindness.*

The great majority of cases of colour-blindness occur in persons of the male sex. I shall therefore describe the male cases known to me first.

Case I.—Mr D., a middle-aged gentleman, discovered in boyhood the peculiarity of his vision in reference to colours, from the disagreement between himself and others, as to the names to be given to the strands of a partiecoloured string with which he was flying a kite. He made known his case to me; and as he attended my lectures last winter, I had many opportunities of testing his vision. The following is his own account of matters, drawn up at my request:—

"As far as I can tell, the following expresses my experience as to colours. Yellow is the brightest colour; blue nearly as bright. These two are the only ones I see distinctly in the rainbow. Red I can distinguish when bright, but delicate shades I confound with stone colour or grey. Green I have no distinct conception of. According to its different shades, it appears black, brown, red, yellow, blue, and grey.

"I cannot distinguish at any distance the ripe cherries on a tree, or strawberries, from their leaves. The flowers of a scarlet geranium I cannot see distinctly at a distance by daylight; but by candlelight there is a marked contrast between them and the leaves.

"I have no conception of what is meant by complementary colours, or of the agreement of different colours when blended together, as for instance what kind of a carpet accords with red curtains in a room.

"With regard to my want of perception of green, it appears to me that the blue and the yellow rays neutralise each other, and, when in equal proportions, constitute what is really no colour, varying all the way from a very light drab or grey to a dingy black. When the blue rays predominate, it appears a blue drab; and when the yellow rays are in excess, it appears a yellow drab. When the blue and yellow are properly blended, a lady's green silk dress appears to me very similar, and no more glaring than a drab silk. The dry dirt of the street I could equally suppose to be green.

"I also confound red and brown frequently. I could not distinguish between treacle and blood spilt in a road by daylight, though I believe I could by candlelight."

Mr D., it will be seen, like the majority of the colour-blind, sees only blue and yellow in the solar spectrum. He would be set down by many as *identifying* red with green; but in reality red when vivid, fully illuminated, and not far removed from the eye, is for him an actual colour; whilst green is not its equivalent, for it is not

one of the three female cases referred to in the sequel; that of seven medical men, colour-blind in different degrees, six answer to the said letter; and that, altogether, I have fifteen examples of the occurrence of this initial, whilst two of the most celebrated cases, described by other authors, rank under it also. This list does not include relatives; and only one surname occurs twice, there being sixteen separate surnames, whilst the most common name that occurs under this letter is not represented.

uniformly confounded with red or any other single colour, but simulates many, and frequently appears black, *i.e.*, makes no luminous impression upon the retina. Mr D., indeed, is certain that he often sees red quite distinctly, but he is not certain that he ever saw green; all colours, accordingly, on which he cannot at once pronounce, he sets aside as probably green.

This gentleman is an educated, highly intelligent person, and he allowed me to test his peculiarity of vision in as many ways as I pleased.

One of the modes which I adopted, was to ask him to assign names to the colour-diagrams in Mr D. R. Hay's "Nomenclature of Colours" (second edition). He has correctly distinguished the *yellows*, and has not mistaken other colours for them, either by daylight or candlelight. The *blues* are also rightly defined by daylight, but other colours are mistaken for them, as the purple of plate 2, which is called *dull blue;* the lilacs of plate 8, which are called *dingy blues;* and the blue-greens of plate 15, which are called *bluish-red.* By candlelight the green of plate 2 is called *blue;* the blue-greens of plate 5, *blue;* and the blue-greens of plate 11, *reddish-blue* and *blue.*

The bright reds are distinctly discriminated both by daylight and candlelight; but, as implied in the last paragraph, bluish-greens are mistaken for bluish-reds; and, as the sequel will show, certain shades of red and green appear identical.

Greens appear under all names. Thus the pure greens of Mr Hay's first and second plates are referred to as "reddish dark drab" and "light brown" by daylight, and as "reddish-blue" and "blue" by candlelight. The pale greens of plate 6 are pronounced to be "drabs" by daylight, and "drabs or greens" by candlelight. The *olives* of plates 5, 8, and 19 are styled, as seen by daylight, "browns;" and plate 23, which contains three shades of red and three of green, is regarded as displaying by daylight six shades of dark crimson, the greens being further described as rather browner than the reds. By candlelight the same colours were seen as three "reds" and three "dark drabs or greens." Plate 29, which contains three different shades of red and three of green, is described as showing, by daylight, six pale reds, and by candlelight three reds and three reddish-blues. In addition, the darker shades of purple are all styled black.

I also tried Mr D. with coloured papers, powders, vegetable infusions, and pieces of glass. Pure blues and yellows he did not mistake, nor bright reds when seen near; but dull or dark reds were confounded with green and sometimes with brown. Among the greens, however, every mixed colour found a place, so that all the paler shades of violet and red-purple, all the russets, yellowish-browns, greys, and neutral tints were arranged together, and along with the true greens, regarded as shades of one colour, which was by preference styled *drab.*

Mr D.'s vision, except in regard to colour, is perfect. His eyes, which were examined by my friend Mr Walker the eye-surgeon, are quite healthy. The iris is grey; the pupil does not show so deep a black as the majority of eyes do, in consequence, as Mr Walker thinks, of a deficiency of the *pigmentum nigrum* of the choroid. Mr D.'s father, two brothers, one sister and her son, have exhibited a similar peculiarity in the perception of colour, but it does not appear in his children.

Case II.—Mr P., æt. 28, unexpectedly discovered his defect in the discernment of colours, in consequence of a piece of enamel which he had prepared, and believed to be pearl or milk-white, being pronounced by others to be decidedly green. He was with difficulty convinced of this; but he gradually became satisfied of his peculiarity of vision, which has betrayed him into many inconvenient mistakes. Last winter he worked for five months in my laboratory, and sometime elapsed before I discovered his colour-blindness, which he was not ready to acknowledge, and could to a great extent conceal, by his sagacity in observing those properties of bodies which are not affected by colour. But as colour is frequently the only criterion by which chemical compounds can be distinguished from each other in the course of analysis, and as he was a thoroughly conscientious worker, he could not avoid frequently appealing to others for assurance regarding questionable tints; and it was in reply to a recommendation of mine, that he should train his own eye to appreciate colours, and not look to assistance from the eyes of others, that he made known to me his colour-blindness. The following is his own account of his case:—

"I have most difficulty in distinguishing greens, except when they are of a medium tint, and very pure. When dark they appear brown or black mixed with blue; and when light, where the yellow predominates, I distinguish nothing but yellow.

"In the spectrum and rainbow I only see two colours, blue and yellow. I am very uncertain about any colour, when either very dark or very light. Surface has a considerable influence in determining my judgment. I distinguish bright and transparent colours best.

"In going over the diagrams in Mr Hay's work ("Nomenclature of Colours," second edition), I find that I give the same colour a different name on different occasions.

"Artificial light causes some green colours to appear blue, and does not assist me in distinguishing other colours."

It will be seen from this account, in spite of its brevity, that Mr P.'s case is worse than Mr D.'s; and as both gentlemen examined colours together in my presence, I could fully compare their cases. I did not ask Mr P. to name many of Mr Hay's colour-diagrams; but here are a few, as determined by him. The green of plate 1 he distinguished rightly by daylight, but described by gaslight as "blue and brown."

In plate 2d, as seen by gaslight, the hue called by Mr Hay *citrine* is described as green, and the true green is named *brown;* russet is described as *red;* and purple as *red and black;* olive as *blue and black*, and orange as *dark red.* In plate 11th, *myrtle green* is left unnamed by daylight, and a darker shade of blue-green is described as *red and blue.* Both are described by gaslight as *blue and grey.* In plate 13th, the lightest of three shades of yellow-green (pomona-green) is called "*orange*" by daylight; and the darker shades are described as "*red and brown.*" By gaslight the first appeared "*grey and yellow*," the others "*grey and blue.*"

From this account, it should seem that artificial light makes a greater difference in Mr P.'s apprehension of colours than would be inferred from his own account; but it must be remembered, on the other hand, that as he does not uniformly misname colours, it is difficult to be certain how far this element of uncertainty affects the results obtained with different lights.

I made many trials in other ways with Mr P. What struck me most in his case, although it seems likely that it is a general accompaniment of the extremer forms of colour-blindness, was the exhibition of a feeble hold upon colour, as a quality of bodies. Apart altogether from confounding one colour with another, Mr P. frequently hesitates to give any name whatever to bright secondary colours, such as purple and green, and if one is suddenly shown him, or if many colours of any degree are shown at once, he totally declines to venture upon names. Thus, on some occasions he has distinguished red and green liquids from each other, and on others has confounded them. Red lead he pronounced to be red, but he could give no name to the colour of vermilion. Small scales of copper-red tinsel, exhibiting a bright metallic lustre, he thought showed *every* colour. Red oxide of iron he recognised as reddish-brown, but he could not describe the colour of the nearly similar brown, or puce oxide of lead. The green oxide of chromium he pronounced on one occasion to be black, and on another to be brown. Grass appears to him sometimes green, but generally yellow, and he knows only a difference of shade between ripe and unripe corn.

Two other points in connection with Mr P.'s case appear worth notice. The spectacle of many bright colours exhibited together, which is a source of pleasure to those who have a normal perception of them, painfully distracted this gentleman, and any lengthened effort to match or arrange colours invariably produced headache.

On the other hand, he unconsciously betrayed an effort to supplement his defective vision of colours by all secondary aids. If coloured papers were shown him he fixed upon any difference in shape, smoothness, or configuration, which they presented, and when they were shown him again, recognised them by differences which would have escaped most other eyes. He would frequently, accordingly, have appeared to a stranger to recognise colours, where in reality he was only recalling the form or condition of surface of

the coloured body. If liquids were shown him, a difference in transparency caught his eye, and he set down the most transparent as metallic solutions, and the least transparent as vegetable infusions. Of the last he knew that the one most likely to be found in a laboratory was infusion of litmus, so that he had only red or blue to choose between, as the colour of the muddier liquid. But, when perceiving this, I placed before him an acid and an alkaline infusion of the purple cabbage, each equally muddy, he would not speak confidently as to a difference between the bright red of the one, and the bright green of the other.

With all this inability to distinguish between colours, Mr P. was conscious of no difficulty in arranging shades of the same colour, or of different colours, according to their intensity. Such a power is possessed by the great majority of colour-blind persons; but how far their arrangement of shades of colour would satisfy a normal eye, is a question interesting in many ways which I shall leave unnoticed in this place.

Mr Walker, at my request, examined Mr P.'s eyes, and found them quite natural, the pupil presenting the same grey colour as in Mr D. The iris has that light hazel or golden colour which Wartmann[1] thinks has some claims to be regarded as a characteristic sign of colour-blindness. Vision was perfect, and could be exercised in the presence of a very faint light, as Mr P. had observed, whilst working as an amateur photographer. He was a good draughtsman, a very good manipulator, and except where colour was concerned, had a trained and accurate eye.

Case III.—Mr W. L. Hughes, learning that I was interested in colour-blindness, kindly made his case known to me, and allowed me to give his name. He is at present studying medicine at the University of Edinburgh, but he followed for some years the profession of civil engineer, and was trained as a draughtsman. He has thus been accustomed, for years, to use colours, and was the prize student of his class as a sketcher from nature. He discovered his peculiarity of vision some six years ago, and found it specially inconvenient when drawing sections, from his constant liability to confound red with black. His eye is natural and healthy; the iris is dark grey; vision apart from colour is perfect; and he is long-sighted. In the rainbow he sees blue, yellow, and orange. He is doubtful whether he sees other colours in it, except red, to which he is not altogether insensible. Blue he regards as the colour which he is least liable to confound with others, and red as his great stumbling-block. He cannot, unless near them, distinguish flowers with red petals, from the accompanying green leaves.

On asking Mr Hughes to give names to Mr Hay's colour-diagrams, he erred most between dark greens and red browns.

[1] Taylor's Scientific Mem., 1846. P. 171.

When I showed him colonred powders he pointed to green oxide of chromium and red oxide of iron, as shades of the same colour. He also confounded dark reds with browns. When asked to select from a number of pieces of coloured glass all the specimens which were red, the majority were rightly chosen, but two or three were green; and in the same way, when assorting greens, he plaeed a few reds among them.

This gentleman has paid a good deal of attention to chemistry, bnt the colours of precipitates have been a constant cause of perplexity to him, and he feels equally uneertain as to the action of acids and alkalies on vegetable eolonrs. He has further noticed that he is liable to confound pink with light blue, and that by artificial light greens acquire a blue tint.

Unlike most eolonr-blind persons whom I have conversed with, Mr Hughes is exceedingly prompt in his jndgments on colours, and adheres firmly to the naines he first gives them. His case is a well marked and interesting one, for it will be seen that he confounds bright red with bright green, ruddy brown with dark green, pink with pale blne, brown with red, and what, perhaps, is rarest of all, black with red. He gave me a very interesting illustration of the extent of his eolour-blindness in reference to red and green. When acting as assistant to the engineer of the Granton railway, he frequently returned in the evening from Granton to Edinburgh on one of the engines, without, however, taking any part in managing it. On these occasions he observed, that although his undivided attention was directed towards the signal-lamps, the light of whieh was visible to him a long way off, he could not, till he was close upon them, distinguish whether they were red or green. He feels certain that he could tell a blue from a red light at a distance which would make green and red appear the same. He has no relatives with a defective sense of colour.

Case IV.—Dr William Bryce, one of the four prize medallists among the Edinburgh gradnates in medicine of this year, was introdnced to me by Mr D. (Case I.) as one afflicted like himself, but not so severely. Dr Bryce (who allows me to give his name) has been aware of his defeet for some years, and found it specially inconvenient when engaged as a teacher of chemistry. He had frequently to ask, instead of telling his pnpils, what the colours of precipitates were, and he was nncertain as to the full action of acids on litmus, and still more as to that of alkalies on tnrmeric.

His eyes had suffered a little from over-stndy, but vision is excellent. The iris is hazel, and he is long-sighted. In the rainbow he sees blne and yellow, but so far as he remembers no other colours; certainly not red or green. In natural objects he distinguishes blue and yellow readily, but he is very nncertain as to red and green.

I had but one interview with this gentleman, and was not able to examine his case minutely, but its characters are sufficiently marked.

At first it seemed but a slight one, for he readily distinguished bright red, and bright green linen and glass, when held near to the eye in full sunshine. The darker shades of these colours, however, stumbled him. He could see no difference between olive and russet, either on broad cloth or on paper, and three yellow greens and three red purples (Mr Hay's 13th plate, Nomenclature of Colours) appeared to him identical. He also confounded purples with browns.

I might have supposed this the extent of his colour-blindness, had he not observed to me that he was not nearly so bad as Mr D. This led me to point to a bed of scarlet geraniums about forty feet distant from the window at which we were sitting, and to remark, that though the sun was shining so brightly on them, Mr D. would be unable to distinguish the petals from the leaves. To my surprise Dr Bryce proved to be in the same predicament. With difficulty he made out the flowers, but he could not distinguish their colour. I then directed his attention to a single scarlet verbena, distant only twenty feet from the window, and asked if that plant was in flower. He replied in the affirmative, and that it was one of the *cruciferae:* its colour he hesitatingly added was yellow: it was in reality one of the reddest shades of scarlet.

I mention these apparently trivial circumstances because they lead to a conclusion of great importance in reference to the use of coloured signals on railways and elsewhere, which all the records of colour-blindness will, I apprehend, be found to justify. The majority even of colour-blind persons are able to distinguish bright red from bright green, when these are *near the eye* and well illuminated, but the power of distinguishing between these colours diminishes with great rapidity when they are removed to a distance from the eye, so that a separation of a few feet or a few yards, according to the severity of the case, abolishes all sense of distinction between red and green. Further, those who are thus quickly put out by distance in their discrimination of these colours, may be detected by their inability to distinguish close at hand russets and ruddy browns from olives and other dark greens. And as the coloured day-signals on railways, especially the flags, which alone are available in some of the most pressing emergencies, soon tarnish and darken, the effect of time is to change light reds and greens into much darker shades, and thereby continually to diminish the distance (small at the best) at which the two danger-signals can be distinguished from each other by a colour-blind observer. I shall return to this topic in another part of the paper.

Case V.—Dr C. has long been aware of his inability to name colours so as to satisfy others, and has tried in vain to cure himself of his liability to error. So far as I had an opportunity of examining this gentleman I found him call four shades of purple, three of which were red purples, *brown;* four shades of olive he styled also *brown;* and russet or ruddy brown he pronounced to be *green.*

Three shades of pale azure blue, and three shades of brown, he also pronounced to be all *green*. I did not detect any confusion between bright red and bright green, but he counted them among his difficult colours, and regarded blue and yellow as the colours most easily distinguished.

This case, it will be seen, presents little remarkable, and I would not have recorded it were it not that it is interesting in a statistical point of view, as I shall have occasion afterwards to notice more specially. Dr C. is one of three medical officers attached to a public institution, and another of them is colour-blind as well as he.

Case VI.—Dr E., the colleague of Dr C. referred to in last paragraph, is in several respects an interesting example of colour-blindness. Like many other colour-blind persons, he is a great lover of the fine arts, and a skilful draughtsman. He was led in consequence, early in life, to discover his inability to arrange his own palette, and was accustomed to rely upon a relative to select his colours, whilst he had no difficulty in graduating their shades. His eye is natural and quite healthy; the iris large and dark brown; the pupil very dark, and vision apart from colour perfect. In the rainbow he distinguishes blue, yellow, and orange. Green he never sees in it, and he is very uncertain as to red. In coloured objects he has no difficulty with blue or yellow, but he stumbles at red and green, and olive and brown. The reddening action of an acid on blue litmus paper is invisible to him; he has no difficulty, however, in observing the action of an alkali on turmeric paper.

Reds and greens he does not always mistake; but they are frequently undistinguishable as separate colours, especially on such surfaces as those of moss and of velvet. Green moss, indeed, and red and green velvet make the same impression on his eye, so far as colour is concerned. He is foiled also by worsteds of these colours; and on one occasion betrayed his peculiarity of vision by his inability to see the contrast between the scarlet berries and green leaves of the mountain ash. On another occasion, he was surprised to find on returning home from a journey, that a letter which he had written during his absence was one half in black and the other in red ink.

A red brick house, which to others is a conspicuous object in the landscape, even at a great distance, is to him an inconspicuous one, and made out with difficulty solely by its form.

These results of his experience were confirmed upon trial. I noticed also that ruddy browns were confounded with olive greens; by candlelight bluish greens were said to look bluer than by daylight, and the contrast between red flowers and their leaves was much more marked than by daylight.

What interested me most in this case was the occurrence of colour-blindness in a friend, whom I had known intimately for many years without discovering or suspecting that he laboured under it, although

we seldom met latterly without exploring together the beauties of his flower-garden. From his fondness for paintings, he was the last person I thought of as likely to be colour-blind, and it was my request that he would look out for cases among his patients that led him to tell me that "it was not necessary in seeking for them to go beyond the doctor." He afterwards added that he had not been conscious of his defect for more than thirty years, without finding out many ways of supplementing and concealing it, so that although indifferent to its being known, it was known to few. I mention this because it has an important bearing on the statistics of colour-blindness. I have been frequently cautioned against being deceived by pretenders to this affection, but few have apprehended that true cases might be concealed. Yet there can be little question that colour-blindness occurs more frequently among females than the published records indicate, and that there is more reason to fear the concealment than the feigning of cases by them. The majority of men set little value on the possession of a nice sense of colour, but women highly value it, and cannot be expected to be ready to confess to its want. Colour-blindness can be as readily detected in them as in men, when an opportunity of testing their sense of colour is afforded, but cases far more rarely present themselves where it is worth while to institute a formal examination.

Case VII.—Dr K., a medical man, aged about 40, has described his own case so fully in the letter which I subjoin, that it demands scarcely any commentary. After stating that, in its general features, his colour-blindness resembles that of Dalton, he continues :—

"I have, from a very early age, made great efforts to overcome this defect by studying works and papers on colour, among which I derived great assistance from Syme's Nomenclature of Colours, and Hay's Harmony of Colouring —indeed, in 1833, I brought these two works under the notice of Chevreul, who was then engaged in the investigation of this curious subject. To endeavour to familiarize my eye to the primary and prismatic colours, I keep in my writing desk, and look almost daily at, a chart of the primary and prismatic colours. These, I think, I know on the card, but I make sad blunders when I leave the card and look at silks, cloths, powders, fluids, or flowers. Indeed, *I dare not name any colour*, and endeavour at all times to describe objects by other characters than those of colour.

"When a boy at school, my attention was directed to my want of knowledge of colour by finding I could not see what my father called the *bright red* berries of the holly. When other children easily found out the trees which were loaded with ripe cherries, I never could till I came so near the tree as to detect the form of the fruit. The discovery of this defect in vision distressed my father exceedingly, and he endeavoured to cultivate in me a knowledge of colour by giving me lessons in painting, making coloured charts for me of the prismatic and other colours, wishing to believe that the defect resulted from want of education in colour, not from a visual defect. I destroyed many a painting of flowers, etc., by putting on wrong colours, as blues for purples, green for some kinds of red, and yellow for others. I still remember the surprise he exhibited when he found I could not detect a red cloak spread over a hedge, across a narrow field—hedge and cloak appeared to me the same exact hue, and they do so to this day.

"Blue and yellow are to me the brightest of colours. Red (that is scarlet) is to me a pleasing sober colour, which refreshes my eye as much as green; indeed I cannot tell any difference in colour between certain shades of these. Red sealing wax and grass, for instance, are absolutely the same exact colour. Some shades of brown, green, and red, I cannot detect to be different. Prussian blue and rouge have the same hue. A rose, the lips, a ruddy complexion, and the face of a man discoloured by nitrate of silver, are to my eyes absolutely the same. Yet my eye can appreciate most delicately the various shades of all these colours, but they are all to me but shades of *one* colour, and that colour varieties of what I see in the pure deep sky or in Prussian blue—in fact, blue in various dilutions. Red hot coals and gamboge yellow are to me identical in colour. Infusion of red cabbage deepened by alkalies, or reddened by acids, to me exhibits *no change of colour*, but only a greater intensity or depth of colour in the acid jar—the actual colour remains absolutely the same. I cannot detect cherries, strawberries, or the red fruits from the leaves but by their form.

"In purchases I have consequently made many mistakes. For instance, I bought a red dress thinking it a green one. I have, on more than one occasion, bought red and green trousers thinking they were brown, and had to get them dyed afterwards to get them worn. In Paris, I bought a red cap to wear instead of a hat, thinking it a green one; in fact, I could give very many instances of similar mistakes.

"The only fact which somewhat staggered me relative to phrenology was, that a phrenologist, then unknown to me, now a valued friend, asked me one day to answer him candidly whether I knew colour, as in me the bump of colour was absent. Several phrenologists who have seen my head since have agreed as to the absence of the so-called bump.

"As to hereditary transmission I can say nothing. So far as known to me none of my relatives had any defect in the perception of colour. My three eldest children distinguish colours accurately; it would be premature to speak of the others who are under six years.

"I believe the affection to be much more common than is imagined. In the cases where I made mistakes in purchases, the shopmen who served me could not put me right; for, knowing my defect, I always took especial care to ask what the colour was lest I should make a blunder."

In the preceding explicit account, Dr K. has, in addition to direct statement, supplied an incidental proof of his colour-blindness. He refers to infusion of red cabbage as being deepened in colour by alkalies; but this infusion, which is originally purple, is not rendered darker by alkalies, but is changed into a bright green. An equally striking, and withal amusing, evidence of inability to distinguish colours is afforded by the chart of prismatic colours to which Dr K. alludes. He was adventurous enough to prepare it himself, and the result may be anticipated; a youthful member of his family soon informed him that one of the spaces was wrongly coloured; and on asking sight of the chart I found that what was called the violet band was a full crimson, so that both extremities of the prismatic spectrum were represented as red.

Such a chart could plainly but increase the evil which it hoped to cure. It supplies a new occasion for the query, "quis custodiet ipsos custodes?"

Dr K.'s inference that the shopmen in warehouses where coloured goods are sold are frequently unable to distinguish colours, is founded

on the fact, that although they were asked to show him only red silks, *ex. gr.*, he was allowed to purchase a green one; but this inference is perhaps scarcely warranted; for a salesman who has exhausted his display of goods of one colour without securing a purchase, very naturally produces goods of a different colour, and might reasonably infer that his customer had only changed his mind when he selected another tint than that which he inquired for at first. But it is quite certain that dyers, painters, weavers, clothiers, and the members of other callings much conversant with colour, are not unfrequently colour-blind. I myself have very recently been offered "any reasonable fee" if I would cure a worthy working tailor of almost total inability to distinguish colours. Dr K. may have encountered a similar case, for I know of cases among haberdashers and silkmercers; and on inquiring at one of the latter, who had served under a colour-blind master, and thereby had his attention directed to the matter, what became of those haberdashers who could not distinguish colours, he made the unexpected reply, "that they generally ended in mourning warehouses."

The following is the most marked example of colour-blindness which has come under my notice, and has not, so far as I am aware, been exceeded in severity by any case on record.

CASE VIII.—Dr Y., æt. 27, early became aware of his inability to distinguish colours, and has cultivated painting in the hope of curing or diminishing his defect, but without any success. Mr Walker reports his eye to be quite healthy; the iris is dark grey; the pupil unusually black. He has himself favoured me with an account of his case, but as he very strongly realizes the want of a common language between himself and those who have not his defect in distinguishing colours, he regards this account as hopelessly imperfect.

"I must again apologise to you for delaying so long to write to you: I feel as if I could not describe properly my ideas, and also that you cannot meet me on any neutral ground.

"You are already aware of some of the peculiarities in my case, but I may as well answer your questions. The colour of my eyes is bluish grey, with a very dark pupil; the quality of vision, independent of colour, is first-rate,—I may say faultless, and my idea of outline is good. The colours I see in the rainbow are blue and yellow. Crystals examined by polarised light present to my eye the same appearance as to yours—most likely, that is to say, I see the yellow and blue, the red and green, and on turning the prism round I see them changing, but I cannot retain in my eye the red and green, and could not tell them on a piece of cloth the next minute.

"The colours which I distinguish best on natural objects such as cloths, glass, etc., I think are yellow and blue, the worst are red and green. Yet when I try to answer your two questions, which I must run together, 'What colours are confounded with each other, or supposed identical or undistinguishable?' and 'What mistakes have been made in reference to colours?' I feel that I may be said not to recognise any colour. In the first place, I never could recognise corn whether it was yellow or green, the green appearing only as a darker shade of yellow. Green and red I cannot distinguish from each other. Red I never saw in the fire, gas, candles, etc., only yellow and blue.

Red cabbage growing, pickled, or in infusion, are all the most beautiful blues I can conceive, and it was by not observing any change by acids in the infusion of red cabbage, when attending Professor Hope's chemistry class, where I used to stare for the whole hour expecting to see the change, that I first became fully convinced of my great defect. Red, again, in the lips, cheeks, nose, roses (red), gooseberries, inflammations, and the like, looks blue to me! —(I never saw a red rose in my life), and yet on recently taking up an oil-paint, to illustrate to another my conception of the colour of the lips, you will be astonished to hear that I took up a green (*terre verte*). On another occasion I was very much annoyed at a little boy who could tell a blue line of water-colour, drawn across my finger, from blood; I could see no difference. Strawberries, cherries, etc., I can recognise without the slightest difficulty, but I don't trouble myself about their colour; I see only a difference as regards what I call *shade*. Pinks, lilacs, purples, and blues, are all the same colour, only differing in intensity. Browns, russets, maroons, olives, citrines, and a host of others, are just anything that I can guess at, but I never get further than red, brown, or green. The names of the other colours I don't think I ever uttered. Indeed I never speak of colours unless I cannot avoid it, and the only practical mistake I ever made in regard to them was purchasing a purple neckcloth under the impression that it was black. That was the only mistake; for a good reason, I never bought a coloured piece of dress, *alone*, either before or since. I may mention that the same colour, when presented to my eye on different objects, especially with unlike surfaces, often, I may say generally, appears quite different on each.

"I have now given you the best account I can of my case. It appears to myself, on reading it over, very absurd, and would lead one to ask, 'What can he see?' Yet I have the firm idea and *feeling* in my own mind, that I *see* colours the same, and as distinctly as you do, but they produce no lasting effect on the eye at all, and I cannot recognise them again."

This gentleman has not, in any respect, exaggerated his difficulty with colours. I have had various opportunities of testing his colour-blindness, both before and since he wrote the account given above. The result of one or two trials will best illustrate his condition. A piece of railway red-signal glass, and another of green-signal glass, held up together, close to the eye in daylight, appeared to be shades of the same colour. He thought, nevertheless, that he could distinguish green glass; for having, shortly before this trial, glazed a picture with bottle-green glass, he endeavoured to familiarize his eye with the colour so as to guard against committing the mistake again. However, when asked to select from a number of pieces of coloured glass, those which were green, he placed side by side, green, red, brown, yellow, claret, and pink; and when asked to state which appeared to him the purest or greenest green, he at once selected the claret-coloured glass.

On another occasion, when requested to match coloured worsteds, he placed the full reds and greens together, and put by itself a skein of salmon-coloured[1] wool as bright yellow. In different pieces of worsted-work he gave the same name to red and to green, but was not generally more disposed to call the supposed single colour by

[1] It may be as well to mention, that the salmon-colour referred to in the text is a light shade of orange, taking its name from the flesh, not the scales, of the salmon.

the one name than by the other. This confusion of red and green was most marked when many shades of both graduating into each other occurred in one pattern. Dr Y. was uncertain, then, what and how many colours were before him, and was reluctant to name any.

Those trials were by daylight. By gaslight much fewer mistakes were made. The railway signal-glasses were distinguished and rightly named, and nearly all the deep red and green pieces of glasses were rightly sorted, so long as they were examined by transmitted light, but when laid upon white paper and observed by reflected light, these colours were again confounded; and the paler shades of coloured glass, in whichever way examined, were as much misarranged as by daylight.

In like manner, when the red and green skeins of worsted which, by daylight, had been put in one bundle by Dr Y., were placed before him by gaslight, he picked out the greens and placed them apart; and the salmon-coloured wool he pronounced to be no longer bright yellow, but entitled to a doubtful place among the reds. Still, however, he could see no difference in many of the worked patterns between the purest reds and greens, although some of the latter appeared now to him blue.

He has had occasion, also, recently to observe, that the difference between red and black, which, as occurring in the leather bindings of church books, is inappreciable to him through the day, can be readily discerned by gaslight.

This gentleman's case is interesting as exhibiting a colour-blindness so entire, that he is not positively certain as to any colour, and, as he said himself, could not in a court of justice speak on oath to one. He is not alone in this respect, and the fact has an important bearing on questions both of medical and general jurisprudence.

Dr Y.'s case also is an extreme one, for though vision otherwise is perfect, the purest reds and greens are not distinguished as different colours, even when close to the eye, and fully illuminated. Further; like most of his fellow-sufferers, he distinguishes colours better by artificial than by daylight, but he errs in the same way with both.

He is, moreover, a striking example of the limitation which colour-blindness sets in the way of scientific study. He was stumbled at the very threshold of chemistry by his inability to make use of colour, as a distinguishing character of bodies. Whole departments of Natural History were in the same way barred to him; and he is deprived of those important aids towards detecting disease which are furnished by colour to other physicians. For him, *ex. gr.*, there is, strictly speaking, no such thing as *scarlet* fever, for he never saw scarlet in his life; and he would distinguish no malady by such a name as *cyanosis*.

From the cases reported by others, I select the more important.

The majority of them are the volunteered confessions of sufferers from colour-blindness, who communicated to me in writing their condition. They are valuable as independent reports, not sent in answer to questions, and free from any bias furnished by me. The first, which is dated from London, is interesting as revealing the experience of one who counts himself not a sufferer, but a gainer, by his colour-blindness. Mr R. writes thus:—

Case IX.—"Having read your letter in the 'Athenaeum' of the 2d April (1853), and your request for information of unpublished cases of colour-blindness, I beg to offer some particulars of my own case, trusting it may be of use to you. I am an engraver; and, strange as it may appear, my defective vision is, to a certain extent, a useful and valuable quality. Thus: an engraver has two negative colours to deal with, *i. e.* white and black. Now, when I look at a picture, I see it only in white and black, or light and shade; and any want of harmony in the colouring of a picture is immediately made manifest by a corresponding discord in the arrangement of its light and shade, or, as artists term it, the *effect*. I find, at times, many of my brother-engravers in doubt how to translate certain colours of pictures, which to me are matters of decided certainty and ease. Thus to me it is valuable. From my childhood, and I am now in my fortieth year, I have been totally unable to retain certain colours in my mind, nor able to give their names when shown to me a second time. This defect applies more particularly to compound colours, such as green, purple, orange, and brown (this colour I can never define); also the difference between pink and pale blue, reds and yellows, blues and greens, reds and greens; but the appreciation of the various shades of colours (or the weight of colours, as I may term it) is exceedingly nice and critical. Sometimes I can see some reds and greens, by lamp-light. A few years ago I went to a draper's to buy some green baize, but unfortunately bought a very bright red, which was excessively painful to my eyes by lamp-light, but agreeable enough by daylight. One of my brothers is equally defective, and I once knew a native of Jersey—an engraver also—(but now dead) who was equally afflicted. My grandfather was very deficient in his knowledge of colours, but I do not know the exact extent."

In a second letter, in reply to one from me, Mr R. writes:—

"When I was a pupil, some twenty years since, Erasmus Wilson (the eminent surgeon), upon a phrenological examination of my head, pronounced me unfit for an artist, because I was so deficient in the organ of colour; but not having felt the inconvenience, but rather the advantage, of this deficiency, I continued the pursuit, perhaps unwisely. The colour of my eye (as I am told) is a deep grey. The sight is natural and rather powerful, for I am able to see very minute objects without assistance from glasses. I can also see very distinctly with but little light.

"With regard to the rainbow, or solar spectrum, I can see clearly all the shades of colour, but I am not able to say which is the red. The violet and yellow are very clear and distinct."

Those who have compared a coloured drawing, or oil painting, with an engraving of it, will appreciate the nature of the difficulty which Mr R. so easily surmounts. In heraldic engraving, for example, a system has long been followed of representing each colour by a separate set of marks. Thus, *blue* is represented by horizontal lines; *red*, by perpendicular lines; *black*, by horizontal

and perpendicular lines; *green*, by diagonal lines from the spectator's left to right; and *purple*, by similar lines from right to left.

This system is to a great extent arbitrary, but it succeeds to some extent in realising to the eye, the difference in tone of different colours. The landscape or figure-engraver has necessarily a much more complex and difficult task to execute; and we cannot wonder that there have been few great engravers.

It comes, however, to be a curious question whether Mr R.'s version of a picture would satisfy one whose perception of colours was perfect. It seems very doubtful if in all respects it would; for it has occurred to Professor Kelland and myself, to observe that colour-blind persons arranged different shades of the same colour according to their intensity, in a series which did not satisfy our eyes; and further, that their arrangement of different colours, according to their intensities, seemed discordant to us. Most persons, I imagine, would find it very difficult to say whether a particular shade of red, *ex. gr.* was as red as a particular shade of green was green; but those who are colour-blind find no difficulty in arranging these colours side by side. Thus: let it be required to imitate in colours a diagram representing the passage from white to black through twelve successive shades, with the further condition that these shall be alternately represented in red and green. To most this would seem an impossible, and withal, an idle undertaking. To a thoroughly colour-blind person, on the other hand, it would be a matter of perfect indifference whether he had to execute the task with six shades of each colour, or with any other relative number of them. The shade is everything to him, the colour nothing; whilst to a normal eye colour and shade are so inseparable, that those who are free from colour-blindness would probably never speak of the greenness of a green as equal to the redness of a red. The case which follows will further illustrate these remarks.

Case X.—Mr N. of Torquay, like Mr R., thinks his colour-blindness of advantage to him when engaged as an amateur artist. His case, which is a very interesting one, I give entire in his own words:—

"I have myself a distinct perception of the whole spectrum, with the exception of the *red* and *green*, which seem to be a very near repetition of the same colours—the difference between them being to my eye much more marked by some accidental variation of tone rather than of *tint*: which to others is frequently imperceptible. The flowers of a fuchsia, the berries of mountain ash, and holly, are scarcely distinguishable to me excepting by their tone or form.

"In crayon-drawing I believe I have, in consequence of this defect, a more just appreciation of light and shadow, and the value of chiaro-scuro in composition, than those who rely upon the effect of colour, in regard to the two tints, to the force of which I am insensible; for instance, although by preference confining myself to greys and neutrals, I have sometimes attempted a coloured landscape, relying upon a friend to select the appropriate crayons in regard to *tint*, whilst I exercised my own judgment in regard to tone; if, as has often been done for experiment, what others call a red crayon, is given to me whilst

executing the foliage of a tree, provided it suited my ideas of depth, I have never distinguished the difference, and have now some drawings with, I am told, bright red intermixed in the foliage ; and in one instance a sea-piece has *light pink* crests to the waves. I selected these myself, the assorted crayons having become intermixed.

"I am not *entirely* insensible to the difference of these colours, but they appear to be infinitely less distinct than what others call merely varying shades of the same colour.

"I can distinguish *scarlet* better than any other shade of red, but the broken colours, as olive, or any approach to brown, chocolate, etc., and the distinction which others recognise between warm and cold colours, I am quite insensible to. Pale green and pink appear to be but slightly different shades of the same colour, as also crimson and dark green.

"By *candlelight* I have a much more vivid appreciation of the difference between these colours—it is then quite an enjoyment to look at a fuchsia, or any other crimson flowers which by day had been lost amongst the leaves. But scarlet is not then so vivid as by sunlight, and, unless the light is very strong, scarlet appears nearly black, much *darker than crimson.* Yellow and blue are very vivid and distinct by daylight, but by candlelight the former becomes pale, and the latter nearly resembles green, which also then becomes much bluer. The distinction between blue and green by artificial light is indeed no greater than between red and green by sunlight.

"A deficiency of daylight also makes scarlet resemble black, the flowers of a geranium which in sunshine appear *much lighter* than the leaves, after sunset appear of a velvetty dark gloss, much darker than the leaves. I remember once having been out with fox-hounds unusually late, but when it was still light enough to ride across the country with safety, I could not in the least distinguish between a scarlet and a black coat, even when quite close to them.

"Whatever this defect arises from, it certainly is not caused by an *insensibility* to the several colours, and their component parts—for instance, in the case of green, I have a very vivid and distinct perception both of yellow and blue, and after the eye has become impressed with either of these, green seems to assume the opposite tint. I was much struck with this last spring on looking for some time upon some peculiarly brilliant double gorse, and then turning the eye to the green lawn, the blooms were most distinctly painted *in blue* upon the grass, remaining for many seconds until the optic nerve resumed its power. It would be curious to ascertain what the effect would be upon a red ground.

"Several other members of my family have the same defect. I recollect the late Lord V—— joking his wife for wearing a *scarlet* dress. She assured him it was bright *green ;* and on comparing notes with him, I found that our defect of vision was precisely the same, although he had been scarcely aware of it till that time.

"My brother, when a child, once picked up a red-hot coal, asking 'what that funny green thing was?' The defect in his case has continued through life. My other two brothers have a very distinct appreciation of these colours, and no *female* member of our family has had the slightest trace of this defect, neither, as you observe, have I ever met with a *female* who was thus affected.

"I have troubled you with these details, of which you may make any use that you please, not mentioning, however, more than initials, and being personally unknown to you, I beg to refer to my brother-in-law, Mr C. K. Sievright, Cargilfield, Trinity, Edinburgh, for my identity, if you attach any value to the above particulars. I would myself on no consideration undertake to distinguish the ordinary signals used on railways, and have frequently remarked, before reading your letter, that this was a very likely source of accidents.

"P.S.—It opens a curious field of speculation whether any two persons call the same colour by the same name. For instance, the sky may appear to me what you would call green, and the grass may appear azure ; we all call these by their conventional names, because the sky is said by our predecessors to be blue,

and the grass green. One of my eyes *by candlelight* has always given a yellow tint to paper, while to the other it is pure white, as it is also to both *together*."

Mr N., it will be seen, exhibits colour-blindness in a very marked degree; and in particular occasionally confounds scarlet with black, *i. e.*, is absolutely blind to scarlet, which affects his eye, as the absence of all colour does a normal eye. The Duke of Bedford is well known to have the same difficulty as Mr N. in distinguishing between the colours of the coats in a hunting-field; Major H., a cavalry officer, tells me that he is in the same predicament, unless the riders are close at hand; and if others of my sufferers from colour-blindness were fox-hunters, they would certainly be equally puzzled.

The distinction between red and green becomes, to a considerable extent, recognisable by Mr N. when they are seen by artificial light. Among the cases already given, Dr E. agrees with this gentleman in finding the contrast between the colours of flowers and of their leaves much more marked by artificial light than by daylight; and cases which follow illustrate the same thing. The partial disappearance or diminution of daylight-colour-blindness, under the influence of gas or lamplight, is a fact of much practical importance in reference to the use of coloured signals, as I shall have occasion hereafter to show.

Mr Amyot, of Diss, Norfolk, has favoured me with the particulars of two cases well known to him. I select the more important of the two.

Case XI.—Mr T. writes as follows:—

"My eyes are grey, and as far as strength of vision and clear definition both of distant and near objects are concerned, I have nothing to complain of; indeed, in both respects, I consider myself better off than my neighbours; neither do I think that I should easily mistake a green for a red, or a red for a green; but if the distant perception of scarlet (or red of that nature) is a necessary qualification for an engine-driver in the conduct of a train, I shall be careful, 'come what come may,' never to offer myself in that capacity to a railway company. A few instances of my difficulties of vision will perhaps serve to give you an idea of its peculiarities. At a distance of about sixty yards it would puzzle me to distinguish the colour of a soldier's coat, although the general outline of the figure would enable me to pronounce upon its being that of a soldier.

"Two years since there was a remarkably fine scarlet anemone in a flower-bed five yards from my dining-room window. It was several times remarked by visitors on account of its brilliancy. It took me always some time to discover it (although I knew its position); my eye resting upon every other colour in the bed before fixing on it. When at last I found it, I could distinguish its colour indeed, but its outline seemed ill-defined, like that of a blot of red ink upon unsized paper.

"My attention has often been called to the beauty of hawthorn trees in full berry, but unless close to them I perceived no red, and even when near enough to see the individual berries, they appear to me for the first few seconds rather black than red, and only gradually assume their red hue; and fields full of scarlet poppies continually escape my notice. I am fond of these colours, however, and at the distance of a few feet can see them well enough,

and I believe when seen by *a transmitted* light (as in a druggist's window), they would strike me when far further removed, than if the light were merely reflected.

"With regard to other colours, my eye is certainly not very sensitive; as very dark green, brown, blue, claret, or black cloths, seem to be cut from the same piece, and the chromatic faults of a bad object-glass to a microscope, do not easily excite my attention."

Mr T. is a striking example of colour-blindness, not in so severe a form as to abolish altogether the perception of the difference between red and green; but such as to render the distinction imperceptible when these colours are removed to the distance of a very few feet from the eye; he plainly would be a most perilous engine-driver. In his case also there is an occasional confusion of scarlet with black, implying a very feeble sensibility of the retina to red. His remark on his indifference to the chromatic faults of a lens, suggests the possibility of colour-blindness proving an advantage to its possessor, in so far as the use of optical instruments is concerned.

We are at great pains and cost to construct achromatic microscopes and telescopes; but if we could make the retina achromatic, we might, for many purposes, dispense with complex lenses to correct the chromatic aberration of light. Perfectly colour-blind persons may yet find themselves in demand as microscopic and telescopic observers, and the highest authorities in their respective departments, so far as form is concerned.

Case XII.—For the following case, occurring in a peer high in her Majesty's naval service, I am indebted to Lord Radstock.

Admiral ———, after referring to the comparative frequency of colour-blindness in members of the peerage, continues:—

"A younger brother of mine, long since dead, was fond of drawing, yet once he painted a *red* tree in a landscape, without being aware that he had done so. I myself, though fond of drawing, never attempted to colour, as I should have done the same, unless the cake of colour had been properly marked. I find that it is not that I do not see a distinction between two colours when placed near each other, as in patterns or bales of cloth, but I should hardly distinguish a red jacket hung on a tree, unless quite fresh from the loom. A red tiled barn I should not distinguish in a landscape, but from knowing tiles are red. The shades of green, of brown, and of red, perplex me most. Bright scarlet is unmistakeable to me, but I chose a pair of green trousers once thinking they were brown. Pink and light blue puzzle me much by daylight: a rose, for example, appears light blue to me. Pink and light yellow are equally puzzling by candlelight. As for signal-lanterns, I should know the difference between red and green if they were shown together, but I should be sorry if the safety of a train depended on my look-out, when one light alone was exhibited, as danger or no danger.

"As a naval officer I should say, that the colour alone of flags can never be relied on as sufficient to distinguish them. I would not dispense with colour, for in particular lights it assists the eye more than shape, especially when flags do not blow out, or are fluttering in the breeze. But, on the other hand, when transparent bunting, which has become worn, is seen against the light, the darker colours are often mistaken for each other, and, therefore, it is essential, and is the practice in the navy to represent different colours in different

patterns, so that each tint is connected with a peculiar shape, and the risk of mistake is lessened."

A naval signal does not, of course, demand such promptitude in discerning and interpreting it as a railway danger-flag; but the opinion of an officer who has seen coloured flags employed in all weathers is of special value in reference to the best mode of lessening the danger on railways from the mistakes of colour-blind signalmen.

CASE XIII.—Professor Y. has favoured me with three letters containing the particulars of his case, the more important features of which I subjoin. He has paid special attention to the difference of his colour-vision in daylight and artificial light, and the results are important:—

"As far," says Mr Y., "as my experience goes, my defect does not apply to shades of colours, but only to colours themselves. I think I am pretty nearly convinced that I see blue and yellow correctly. I can name blues and yellows at once. Yellow I never mistake. Blues I feel sure I know, but purples are apt to appear blue to me. Red, green, and brown are my puzzles. I have sketched in sap-green thinking I was using sepia. But all shades of these colours are not equally difficult to me. It is what seem to me the duller shades that most trouble me. Scarlet I know, because I doubt not there is a good deal of yellow in it. Purples (unless very red purples) annoy me. The reason is, that my sense of blue is so much stronger in daylight, than of red, that it overcomes it. I see the blue in the mixture, while the red scarcely affects my eye. I say in *daylight*, because it is different in candlelight. Flowers that appear to me (on cursory examination) blue in daylight, seem to me in candlelight really red, or rather purple, *i. e.*, flowers that actually are so. A scarlet flower would appear still brighter. I have always delighted in going into a conservatory by candlelight, because then all the purple and red flowers stood out in such brilliant contrast to the green leaves. It is not so in daylight. Then, though I can see them well enough if near, at a little distance the contrast makes no impression on me. With purples in daylight, the blue overcomes the red; in candlelight, the red either overcomes the blue, or appears in its just proportion, I cannot say which. The same sort of greens that appear blue to the generality of eyes by candlelight, also appear blue to me. I think I know no special difference in brown by day and candlelight. A little way back, I have used the expression 'on cursory examination.' I say this, because sometimes by an effort I can name a colour, which, unless I strive to realise it, I might pass over without its making a definite impression on me.

"I can sympathise with your friend (Dr Y.'s case) who *knows* a rose to be red, but always sees it blue, not that I ever see a rose blue, but because I often see purples blue. When blue and red are mixed, the blue is apt to kill the red to my eyes, and yet not so completely, but that if a genuine good blue were put alongside the mixed colour, I could tell which was which, if *asked* to do so; but if not asked, the difference would not strike me.

"With greens I have much less difficulty than with reds. I know a yellow green from a blue green. I can distinguish all the gradations. I see the brightness of the grass and young leaves. Young boxwood is a beautiful bright green. As I write, I can see young boxwood and scarlet poppies from the window. At the distance they appear equally bright and not very dissimilar. Near at hand something would tell me that scarlet is scarlet."

I have had several interviews with Prof. Y. His eyes are greenish grey, and quite healthy. He is long-sighted, and a very accurate observer with trigonometrical instruments. His case is a characteristic, though not extreme one, and is specially interesting as showing that an eye blind to red in certain circumstances by day, perceives that colour distinctly by artificial light.

In addition to those cases, I may briefly refer to some of the particulars connected with others occurring in males, which have come under my notice, but do not call for full discussion.

The following letter from Dr S. speaks for itself:—

"Having seen only a short quotation from your letter in the 'Athenaeum,' I am exceedingly glad to see your paper in the 'Monthly Journal' upon the subject of colour-blindness: for, being myself a subject of this deficiency, and not having met with other cases, my own statement has been received by most with an incredulous smile, and by many with absolute ridicule and disbelief. I rejoice, therefore, that the very similar cases recorded in your paper will tend strongly to throw credit on my own, concerning which I will briefly inform you. Æt. 23. I have known of the defect some ten years, and discovered it by mistakes when entrusted with commissions for coloured purchases. I have been a successful draughtsman and sketcher from nature, but on using water-colours (when not marked with the name) I have even painted trees red. After frequent appeals in the laboratory revealing my want of discernment, having become subject to much annoyance, I formed a collection of all ordinary precipitates, so as by careful observation to recognise them again almost to a certainty, though I dare not name their colours, which became of course a mere matter of memory. This annoyed me much, being very fond of chemistry, and forced me to a confession during examination in London, where a powder was indicated to me only by its colour. I can clearly discern blue and yellow, except in the case of light blue, which may be mistaken for pink, and *vice versa*. I am uncertain as to the action of acids on litmus, and cannot at a little distance distinguish red petals or berries from the leaves of the same plants. I can only remember blue and yellow in the rainbow, and am always puzzled with greens and reds, unless the latter are very bright, and often confound both of these with brown, and some greens with drab. I have a distinct perception of shades, while the colours are still unknown. Having often observed a railway signal light, seen from my window, I am convinced that its colours would be lost upon me, nor dare I trust to their flags. I never venture on the purchase of coloured articles without a companion to appeal to, having made mistakes almost equal to those of Dr K. (Case VII.); and though from theory I believe I understand complementary colours, yet I cannot appreciate them. None of my family are so affected, and some of them are good colourists, but I understand that my maternal grandfather had some similar deficiency. And I am persuaded that it is not uncommon, for the very different and contradictory opinions of those who professed to be judges when I have been in doubt, led me at one time to become almost a sceptic as to whether colour is any general principle, perceptible to and affecting all, and whether the perception of any given colour by different individuals be not as widely different as their characters and thoughts. I am now, however, convinced that such a theory must be erroneous."

Prof. N. (whose case has been referred to by Sir David Brewster), discovered his defect when a student of natural history, by his inability to distinguish the colours of minerals. Blue and yellow he sees distinctly, but carmine-red he confounds with blue. Red

gooseberries till recently appeared altogether blue: latterly "he has observed what he fancies red in them." Pink by daylight seems blue to him, and by gaslight green. He is not certain that he ever saw red. "I suppose," says he, "sometimes that I can distinguish red in some objects, but probably this is from knowing that they are usually of this colour: at any rate, I am quite sure that I should make a dangerous railway signal-man, as I most certainly would not know a red flag from a green one."

Mr George Simson, the artist, tells me that he had a pupil-apprentice whom he released from his engagement, in consequence of finding him copy a brown horse in bluish green, paint the sky rose-colour, and roses blue.

Mr Inglis of Hanover Street had a boy who offered pink and pale green paper as good matches, and brought his master into frequent trouble by binding books in wrong colours. Messrs Grieve and Co. had in their employment a weaver for whom the red and green threads in his web had to be selected by another, as he could not distinguish them.

Mr E. J. Cobbett of London informs me of a carver and gilder known to him, whose father, as well as himself, appear to confound all colours. The son, who is a good draughtsman, painted a head with the face muddy green, and brought to my informant a packet of emerald green, which he conceived to be vermilion. A brother of this person, an artist by profession, knew no difference, by gas-light, between the variously coloured bottles in a druggist's window, and could not distinguish the red from the green signal-lamp at a railway station.

Mr S. of Bishopsgate Street Without, London, has sent me the account of six males known to him—uncles, nephews, and cousins—in one family, who are markedly colour-blind. The parents of the younger parties are quite free from colour-blindness, which has descended to them from their maternal ancestors. They all belong to the Society of Friends, and their mistakes in selecting articles of dress have been rendered specially conspicuous by the preference which members of that religious body give to the least brilliant and most unconspicuous colours. One of their number provided himself with a bottle-green coat, intending to purchase a brown one; and selected for his wife, who desired a dark gown, a scarlet merino. Another, who is an upholsterer, purchased scarlet for drab, and had to rely upon his wife and daughters to select for him the fabrics needed in the course of his profession. A third, who is a farmer, could not tell red apples from the surrounding green leaves, except by their shape. All of them confound red with green, olive with brown, and pink with blue, but they are very expert at matching shades of the same colour. One of the younger men, whose profession requires him to deal much in coloured tissues, has found that the "only way of telling the difference between scarlet and green, or blue and crimson, is to take them into a room lighted with gas or

candles," when the distinction which was invisible by daylight becomes apparent. Olives and browns, however, are as undistinguishable by one light as by another.

My informant also mentions the case of a minister in the Society of Friends, who selected scarlet cloth as the material for a new coat. It is probably not an accidental thing, as I shall endeavour in another place to show, that so many of the followers of George Fox are colour-blind.

The last case in a male I shall mention was communicated to me by the sufferer (as he may with special emphasis be called) himself. He is a tailor's foreman, and was unaware of his defect till four years ago, when he was promoted to his present post, and for the first time had to match colours for the journeymen. He was soon involved in grievous difficulties. The scarlet back of a livery waistcoat was provided with green strings *to match*. A ruddy brown was put side by side with a dark green. A purchaser was informed that a red and blue stripe on a piece of trouser-cloth was all blue; and in general greens were confounded with reds and browns, and crimson with blue. He sent me examples of his "matches," which display a colour-blindness of the extremest kind; and yet he had not been aware of it for years, though working at a calling constantly concerned with colour. These "matches" were accompanied by a letter, in which he says :—

"Perhaps you will be able to discover where the fault lies, and to give me some advice in the matter. This I cannot expect gratuitously, but shall be happy to forward any reasonable charge, and at the same time feel greatly indebted to you, for if I do not improve I must certainly go out of the business."

He adds that he keeps his present place in consequence of his excellence as a cutter; so that he is another example of a good eye for form and outline accompanying blindness to colour.

Cases of Chromato-Pseudopsis in Healthy Females.

So far as I am aware no case of colour-blindness in females has been described in detail. Previous writers on this affection have drawn attention to its rarity among women, and my own experience is exactly to the same effect; although for reasons already given, it probably appears more rare than it is, and chiefly because the value set by women upon a nice appreciation of colours, makes them reluctant to confess that they are not quick or accurate in judging of them. But, on the other hand, the high standard of colour which females acknowledge, enables them more readily than males to detect shortcomings from it; and those who do not come up to it, should at once be discovered by their more fortunate sisters. Yet though I have made inquiry in many quarters, I have not in nine months heard of more than six cases, and I have only had the opportunity

of examining one. I was casually informed by a person who had been a silk mercer, that he was convinced that in certain of the country districts of England, where he had been engaged in business, the peasant women were frequently at fault with colours, and that he had deliberately given them one colour, when asked for another, to test the matter, and no complaint was made. He added, however, that women of the better class, who were conscious of any defect in appreciating colours, were careful to bring a friend with them when making purchases, and thereby escaped detection.

Induced by these statements, I have made inquiry among the silk mercers, fringe makers, and other parties in Edinburgh, who sell coloured goods, but neither from their customers nor from their female attendants, have they been able to furnish me with a single case of colour-blindness, although they are quite accustomed to find young girls much less perfect at matching shades when they first attempt this than they afterwards become. From all these facts the general inference may be drawn, that colour-blindness is much less frequent among females than males; and the certainty of this is put beyond doubt by the fact, that even in families where several of the males are colour-blind, the females generally are normal in vision. Mr D.'s family is the only exception to this among the cases I have reported. One sister of his, as well as his father and two brothers, were colour-blind; and that sister's son is so also. On the other hand, the Rev. Mr E., whose case was communicated to me by Mr Amyot of Diss, has a brother and two uncles colour-blind as well as himself, but his sister has a perfect sense of colour. Mr N. had a brother and a cousin as defective in colour-vision as himself, but his sister has no such defect. The cases referred to by Mr S., as occurring in members of the Society of Friends, embrace two brothers, two uncles, and two cousins, all males, but none of their female relations have anything abnormal in their vision of colour. The Countess of D. inherited colour-blindness from her father, and her son and two nephews are subjects of the same affection, but her daughter's eye is remarkably sensitive and correct for colours. It has been shrewdly observed, accordingly, by an intelligent lady, that women would *cæteris paribus* make safer signallers and signal observers than men, a suggestion worth consideration.

When colour-blindness, however, does occur in females, there is no reason to doubt that it exhibits the same phenomena as in males, as the following cases will illustrate.

Case XIV.—The Countess of D. has been conscious of colour-blindness from early youth. An account of her case was published, I believe, many years ago by Dr Wollaston, but I have not seen it. With the following particulars, I have been favoured by herself, through the good services of Lord Radstock.

Lady D.'s eye is brownish-grey; her vision is excellent both for near and distant things. In the rainbow, she sees only yellow, and

in all objects it is the colour which she pronounces on with most confidence. Blue she sees clearly, but some shades of lilac seem blue: Red, green, black, brown, and lilac, she does not venture to name confidently, and greens and drabs are the same colour. Mountain ash or holly berries are undistinguishable from their foliage. In sorting worsteds, she can place no confidence in herself in choosing, and all the *lightest shades* of colour are liable to be completely mixed up. Mistakes such as have been referred to are daily made.

Lady D. further mentions, that the colours of nature abound in richness to her senses, and the resemblance of pictures and drawings to nature is equally and sensitively appreciated. But she qualifies this in a later communication, by stating that "the *yellow* tints now (October) seen on the trees appear to me exactly the same as those of their spring shades; indeed, I cannot conceive the possibility of any one seeing them to be different." As the terms *yellow* may here be held to include all the autumn tints of the leaves, and therefore various shades of orange, red, russet, and brown, and as these to a greater or less degree seem identical with the yellow-green and the bright green of the spring leaf-tints, there must be a marked colour-blindness in the eye which identifies them.

Lady D.'s father and one of her sons have the same peculiarity of vision, and two nephews possess it at least to the extent of confusing red with green, but her daughter, as already mentioned, is totally free from colour-blindness.

Case XV.—The following case was communicated to me by Mr H. J. Moule, who received the account from the party concerned. She writes as follows:—

"I do not know how to express myself well regarding the loss I am at to distinguish colours, as I hardly understand *how it is* myself, but I will try to do so as clearly as I can. There are many colours the shades of which I confound; these are blue, lilac, pink, and purple, and if the various shades of these colours were put before me, and mixed together, I should be quite confused, and *could not* tell to which each belongs, although *I see* that they are different. In the same way I confound green, brown, and some of the shades of orange. In short, were I to tell the name of any colour correctly, it would be merely guess-work. I can enjoy the beauties of nature, and the varied hues of the trees, etc.; but that there is *some* defect in my vision I am quite aware. Of this, also, I am certain, I can do nothing (or as yet have not been able) to improve it."

This is a well marked case, and from the confusion of green with brown, and purple with blue, it is likely that the writer confounds red with green. It might seem, from one passage, as if she *saw* the different colours, and only had a difficulty with their *names*, but Mr Moule incidentally informs me that, when engaged with coloured worsted work, she always has the skeins *marked*, which shows that the difficulty is a Real not a Nominal one.

Case XVI.—For the next case I am indebted to Mrs Freeman, Mallow, County Cork.

"When a girl, I attended, for a short time, a drawing class at Mr Charles Barber's, Liverpool, who still, I believe, exercises there the profession of artist and drawing-master. I saw there a 'grown up' young lady, whose name I forget, engaged upon a large water-colour landscape, and soon found, with much surprise, that she was entirely unable to judge of the effect of the different colours she used. The master would tell her to rub Prussian blue, red lake and yellow ochre (or some other combination of colours), but he was obliged to mix these in their proper proportions. If the names stamped on each colour were legible, she of course used what she was directed to use, without difficulty; otherwise, she recognised the colours by *the taste*, and I remember Mr Barber often cautioning her against this practice, especially with regard to vermilion and gamboge. As to the mixed tints upon the palette she appeared to have no appreciation at all of their differences, otherwise than that they appeared darker and paler relatively."

This case calls for no comment; it was probably as extreme as any of those recorded in males.

The only case of colour-blindness in a female which I have had an opportunity of personally examining was a somewhat peculiar one. M. F., æt. 16; eye grey; vision perfect; long-sighted; is errand-girl in a fruit and flower shop; and the frequent mistakes which she made in reference to flowers, led to her defective sense of colour being soon detected. She is a quiet, shy girl, slow for her years, but not stupid, and she does not so much err between unlike colours, as come to a tolerably just conclusion regarding them with extreme tardiness. It was difficult to be certain of her true condition, from the incredibly scanty nomenclature of colours which contented her. It did not include the term *green* (not to speak of purple and orange), and even after that word was suggested, and a number of greens were shown her, she continued to call light greens *yellows*, and dark greens *blues;* and to speak of the paler crimsons and pinks as *yellows*. Yet when asked to assort worsteds and pieces of glass according to their colours, she did it upon the whole correctly, only with great slowness, looking long at each colour, and naming it hesitatingly. I came finally to the conclusion that her case included two features: a very slow appreciation of the difference between colours, and an equal difficulty in connecting the impression or conception of a colour with its name. She is thus rather an example of feeble than of false colour-vision; but of this her case is a marked one. To meet with a girl of 16, fond of reading, and intelligent, who could not tell the colour of her dress, and who, after long thinking and looking, was not certain whether to call a particular colour blue, green, or yellow, is not common; and I find that all of her own sex, who are aware of her defect, regard her as a very anomalous person.

Case of Colour-Blindness induced by Cerebral Injury.

I have reserved for separate consideration, a peculiar and exceed-

ingly interesting case of colour-blindness, occurring as the result of a severe accident in the person of a surgeon at present resident in Edinburgh.

Case XVII.—Mr B., who was introduced to me by Mr John Struthers, lecturer on anatomy, studied here some years ago, and afterwards engaged in practice in Yorkshire. In November 1849, he had the misfortune to be thrown from his horse, and was taken up in a nearly insensible condition, labouring under symptoms of concussion of the brain. He was confined to bed for months, and has now a very imperfect recollection of what transpired during the period; but he has kindly procured for me from his medical attendant, Mr Thom of Dobcross, a statement of his condition whilst under his care. From this it appears that after rallying from the collapse which immediately succeeded the accident, he suffered from severe pain in the head, delirium, mental excitation approaching almost to mania, loss of memory, and other symptoms of cerebral disturbance, which did not subside for many months. Eventually Mr B. regained his health and resumed practice. He is not so robust as before, nor is he capable of so much fatigue; neither is his power of mental application, nor his memory so vigorous as it was formerly, but he has wonderfully recovered from the serious accident which befel him. One sense, however, appears to have been irremediably injured. On recovering sufficiently to notice distinctly objects around him, he found that his perception of colours which was formerly normal and acute, had become both weakened and perverted; and it has since continued so.

He has for the present resumed the study of medicine in Edinburgh, and has allowed me to test his vision of colours freely. All coloured objects, he informs me, now seem strange to him. The rainbow is quite destitute of hue, appearing as a white semicircle against the sky, or as a lunar rainbow does to most normal eyes. This absence of colour in the solar spectrum, however, is largely due to the weakening of Mr B.'s colour-vision; for certain of the tints of coloured objects held near to the eye are well enough distinguished, especially yellow and blue. Bright shades alone are pleasant to look at; dark shades appearing "a mass of confusion," and uncomfortable to the eye; red and green in all their shades are undistinguishable from each other. These were Mr B.'s conclusions concerning his own case, and I found them fully confirmed on trial. Bright blue and yellow he never mistook; red and green, I may say, he never knew; and he put aside, as incapable of definition, all the more mixed or composite colours. In short, without multiplying details, it may be stated, that Mr B., in consequence of the accident which befel him, has passed into what is the *congenital* condition of the colour-blind. That he sustained some injury of the brain is his own belief, and will probably be the conclusion of all medical men who read his case, and it points to the probability of pathological inquiry,

yet revealing to us the cerebral or nervous seat of colour-blindness.[1]

It may be worth the attention of medical men, therefore, to note the quality of vision in those who recover from severe concussion of the brain, as compared with its condition before the injury was received; and where opportunity offers to examine the retina and brain, microscopically and otherwise, after death.

In Mr B.'s case the extent to which the power of the eye over colour has been altered, is placed beyond doubt. Whilst formerly a student in Edinburgh, he was known as an excellent anatomist; now he cannot distinguish an artery from a vein by its tint. He was previously fond of sketching in colours, but since his accident he has laid it aside as a hopeless and unpleasant task. Flowers have lost more than half their beauty for him, and he still recalls the shock which he experienced on first entering his garden after his recovery, at finding that a favourite damask rose, had become in all its parts, petals, leaves, and stem of one uniform dull colour; and that variegated flowers, such as carnations, had lost their characteristic tints.

Alone of all the cases which I have recorded, he knows what he loses by his colour-blindness, and is even worse off in some respects than the totally blind; for if they have never witnessed colours, they will not think of these as things they cannot recall; and if they have known them, they can, as the seeing do in dreams, recall them; it may be dimly, but yet on the whole as they are. But for Mr B., the colours which he saw, are not only effaced, but are replaced by tints the most unlike those which they once bore.

III.—*General Conclusions concerning the Colours perceived with most difficulty, or most liable to be confounded with each other by the Colour-Blind.*

In the first section of this paper I have made some observations on the colours most liable to be confounded by the colour-blind. I propose now to consider the subject more fully, with special reference to the conclusions deducible on this point from the cases which I have reported. This may be most conveniently done by making each colour the text for some remarks; and first of the colours generally accepted as primary, viz., red, blue, and yellow.

Confusion of Red, Blue, and Yellow, with each other.

The extent to which the primary colours are confounded with each other, varies very greatly, according to their intensities. It will suf-

[1] Mr Struthers informs me that from the details communicated by Mr Thom. it appears "that there was no fracture of the skull. It was a case of severe concussion, followed by long continued cerebral excitement, but not of an inflammatory type apparently."

fice to regard them as offering themselves to the eye in the three modifications of *full* colours, dark shades and light shades.

So far as I have observed and read, it is not characteristic of colour-blindness to confound one of the full primary colours with one or both of the others. There are persons as already noticed, who are reputed to be unconscious of every colour, and who, of necessity, see no difference between the purest and deepest red, blue, and yellow. But such parties cannot be said to confound these colours with each other. They neither distinguish nor confound them; they simply ignore them.

There are persons also like Mr P. (p. 17), and Dr Y. (p. 25), uncertain as to all colours, and therefore *liable* to confound those which are primary with each other; but on consulting their cases it will be seen that they rarely do confound these, and that their difficulties are between primary colours on the one hand, and secondary or more complex colours on the other. Dr Bryce mistook a very red scarlet for yellow (p. 20), but this was at a distance, and may be explained by supposing that his eye being blind to red, he saw only the yellow in the scarlet. Professor N., however, confounds carmine-red with blue (p. 33), and this appears an undoubted example of the confusion of one pure primary colour with another. Other examples, doubtless may occur, but certainly few eyes are so false in their vision of colour, as to regard as similar or identical chrome-yellow, carmine-red, and ultramarine blue, when these are displayed, undiluted, and undarkened, in white light, such as that of the sun, of the ignited lime-ball, or of the voltaic arc. Full blue and full yellow contrast more strongly in these circumstances with each other, to colour-blind eyes, than red does with either; and it is with blue rather than with yellow (as will appear in the sequel) that red is liable to be confounded.

Shades of the primary colours are greatly more liable to confusion with each other by all eyes than the full colours are. There is a very marked difference as to the point at which eyes reputed normal cease to perceive red, blue or yellow, when these are darkened by the addition of black, or diluted by the addition of white. So far as the deeper shades are concerned, blue suffers first from darkening, and soon becomes undistinguishable from black; red disappears next, and yellow survives longest. To a colour-blind eye, on the other hand, red, which is always the least visible of the primary colours, appears first to become indistinct by darkening, then probably blue, and finally yellow; and all of them become sooner indistinct, *i. e.*, after a smaller amount of darkening, to the abnormal than to the normal eye. This is an important fact which has not hitherto been noted otherwise than incidentally. A review of the cases which I have published, and of those detailed by others, will justify the conclusion that the sensitiveness to colour of a colour-blind eye suffers sooner from the withdrawal of light than that of a normal eye; and the fact is the more interesting that perception of form in

partial darkness appears to abide longest with the abnormal eye. Thus Mr P. states, that he is "very uncertain about any colour when very dark" (and his "very dark" may be measured by his calling oxide of chromium black (p. 17), and that he distinguishes "bright and transparent colours best;" yet, whilst working as an amateur photographer, he found a very faint light, sufficient to see by. Dr Y. (p. 25) regards the quality of his vision, in reference to form and outline as "first-rate," but browns, russets, maroons, olives, citrines, and a host of others, are "anything he can guess at," and purple he confounds with black.

Mr N. is quite insensitive to olive, or anything approaching to brown, chocolate, etc. (P. 29).

Mr T. thinks himself better off than his neighbours, so far "as strength of vision, and clear definition, both of near and distant objects are concerned" (p. 31), yet he states, that "very dark green, brown, blue, claret, or black cloths, seem to be cut from the same piece."

The countess of D. cannot confidently decide between "red, green, black, brown and lilac" (p. 37).

From these cases it will be seen, that dark shades of all colours, compound as well as primary, are confounded with each other by the subjects of Chromato-pseudopsis, and that it is only the expression of a fact to say, that, apart from confounding colours, they become blind to those they can see, in partial darkness, much sooner than others do: or to state the truth otherwise, the diminution or withdrawal of light sooner arrests the sensitiveness of a colour-blind than of a normal eye to colour.

It is more characteristic of a colour-blind eye, however, to confound the light shades of the primary colours than it is to confound their dark shades. When red, blue, or yellow is diluted with white a point is ultimately reached with every eye, at which the excess of uncoloured light accompanying the colour renders the retina insensitive to the impression of the latter. The light shades appear to disappear to a normal eye in the reverse order of the dark shades, yellow being the first to become undistinguishable from white; then red; finally blue. Pale pink and pale yellow are undistinguishable by many eyes, not otherwise faulty in their discrimination of colours; and Wilkie was not the only painter whom Haydon might have reproached for painting his flesh-tints in yellow. Blue, on the other hand, must be very largely diluted before it becomes invisible to normal eyes, or is liable to confusion with light red or yellow. To the colour-blind, again (especially to those who frequently mistake full red), pink and light blue are constant puzzles, and this long before they have undergone great dilution with white. A reference to the cases of Mr Hughes, Dr Y., Prof. N., Mr R., Admiral ——, and the six parties authenticated by Mr S. will illustrate this. Further, cases not unfrequently occur of persons confounding pink and blue, who do not, so far as they are aware,

confound other colours. Of these I have given three examples (p. 12) occurring in dyers.

The pinks thus confounded with blues include diluted crimsons, *i. e.*, red with a little blue in it, as well as diluted reds; and it is not certainly surprising that an eye which cannot distinguish pale blue from pale red, when these are placed side by side, should confound these when they are mingled together. But there is this difference to be noticed between crimson and pure red, that the deeper the latter the less liable is it to confusion with blue equally deep, whereas the deeper (in the sense of the more purple) a crimson, the more undistinguishable does it become from full blue, as will be noticed more at length further on.

Altogether, then, it may with great confidence be stated to be a marked characteristic of colour-blindness to confound with each other the *light* shades of the primary colours, and by the term "light" is not signified a mere tinge of colour. Dr Y., for example, sees roses of all shades of red, *blue* (p. 25); and the skeins of pink and light blue which I have seen put side by side as matches, were, to my own eye, conspicuous for their amount of contrast of colour.

In connection with this matter, I notice that the Countess of D. (p. 37), and Mr P. (p. 16), both mention of their own accord, that pale shades of *all* colours are perplexing to them; and the general conclusion may be drawn, that as a colour-blind eye suffers sooner in sensibility to colour, from the removal or diminution of white light than a normal eye, so it also suffers sooner from an excess of uncoloured light. Its perception of colour is limited in the direction both of dark and of light shades much more narrowly than that of a normal eye, whilst its perception of form and outline is as acute, if not more so, especially when light is feeble.

Confusion of Primary with Complementary Colours—Red with Green; Blue with Orange; Yellow with Purple.

The most important variety of colour-blindness is that which shows itself in the confusion of primary with complementary colours, and especially of red with green. Before discussing at length the difficulties which attend the perception of red, I shall dispose of the little I have to say concerning the other primary colours.

I am not aware of any case having occurred where blue was habitually mistaken for orange; nor have I seen any indications of a tendency to such a confusion among the colour-blind whom I have examined.

The confusion of yellow with purple appears to be equally rare, and I am not aware of any example of its occurrence being on record. The great unlikelihood of its presenting itself had been brought so forcibly before me by Professor Kelland, in some important observations on colour-blindness, which will be given in the sequel, that I had ceased to look for cases, when I unexpectedly encountered, in

quick succession, two examples of at least an approximation to the identification of yellow with its complementary purple. Both occurred in the persons of artillery soldiers at Leith Fort. Whilst testing the colour-vision of one of them, I showed him a square of chrome-yellow paper, which he at once pronounced to be purple. Startled by so unlooked for a reply, I said nothing, but put in his hands a bundle of coloured wools, and begged him to select the purple skeins. The first he selected was chrome-yellow, then he picked orange, pink, crimson, red-purple, and purple-brown, as if he were feeling his way from yellow to purple, which last, however, he did not reach. He stopped at the purple-brown, and continued without saying a word, to retain the yellow skein in his hand as if it came nearest to his idea of purple. I asked him to explain what he understood by this colour, but he could not give any definition of it, and when I showed him one by one the purple skeins, none of which he had selected, and said these were purples, he at once accepted them as such, and pronounced the yellow and orange to be yellows.

This man was very nervous during his examination, and especially at first, but such a condition of discomposure probably favours the manifestation of a latent weakness, and does not lessen the interest of his case. The firm grasp he retained of the yellow skein, his long glances at it before he selected other colours, his apparent contentment with its place in the same bundle with red-purple and purple-brown, and yet his manifest perplexity as to all his colours being the same, and his dead stop and refusal to name them, coupled with his ready reception of a colour the opposite of yellow as purple, are exactly the features of colour-blindness as I have constantly seen it in those who confound red with green.[1]

The other artillery soldier, on being shown a slate-coloured paper, pronounced it to be yellow, but on this name being challenged, described the colour correctly. On asking him why he had previously named it differently, he replied, that on first looking at it it had appeared to him yellow. This perhaps was simply a case, where a fixed gaze on one colour brought up its complementary colour, according to the well-known law of such alternations. But even regarded as such, it is curious, for the man had done no more than glance at the paper when he named it, whereas a normal eye must look long and steadily at a colour to bring into view its complementary; and, moreover, in this case the complementary colour *alone* was seen without a *previous* perception of its primary.

[1] Above 700 soldiers in the Edinburgh garrison were examined as to the quality of their vision of colours, but as they were purposely left in ignorance of the object of the examination, many of them supposed that Mr Dun, who assisted me, and myself were government or military inspectors, and that dismissal from her Majesty's service might follow the discovery of any defect in their eyesight. We did our best to set the men at their ease, but several of them were a good deal discomposed, and a few were somewhat sulky. The particulars of this examination are given in another part of the paper.

Altogether, therefore, both of the cases detailed are probably entitled to rank as examples of a slight or incipient manifestation of a rare variety of colour-blindness, of which more marked cases will be found if sought for.

Confusion of Red with Green.

The confusion of red with green, which first largely attracted attention to colour-blindness, extends, though not equally, to all the shades of both colours; and each is also liable to confusion with other colours, so that the great majority of cases of chromato-pseudopsis group themselves under red or green, or both. I shall first consider the confusion of these colours with each other.

Red, without any tinge of yellow on the one hand, or of blue on the other, is for most persons rather an ideal than a real colour, and there is a very marked difference in the sensitiveness of eyes reputed normal, as to the distinction between red and crimson, red and scarlet, and crimson and scarlet:[1] but on this point it is needless to dwell at length, for all those colours are confounded with green. I wish, however, to notice, that as crimson by the addition of blue, passes insensibly into red-purple; and scarlet by the addition of red into orange, it is to be understood, unless otherwise stated, that by crimson and scarlet are signified always the redder, and generally the reddest shades of these.

No term includes a greater number of different shades of colour than GREEN, chiefly, no doubt, because nature presents to us on every side so great a mass of green, and so many tints of it. I cannot, accordingly, decide what colour exactly is signified by those subjects of colour-blindness, who have communicated to me their cases in writing; but, in general, I intend by green, a mixture of yellow and blue, in which a normal eye sees no excess of either. Very great differences occur in the judgment of different persons as to the preponderance of one or other of its components in a green; and it would be convenient to have a standard shade for this abundant and important colour, such, for example, as the green which is complementary to pure red, *i.e.*, a compound of all the blue and yellow in the solar spectrum. But very few are familiar with this green, and I must leave each normal-eyed reader to choose for himself a shade of this colour free from the least bluish or yellowish tinge.

[1] This is curiously exemplified in the apparent total inability of medical men to determine whether arterial blood is scarlet or crimson. The poets and painters appear to have unanimously decided that it is crimson; whilst the Spanish grandee prides himself on his blood being blue. In reality, blood shows all these colours. Seen through a vein it appears blue; drawn from it, it appears purple; as it undergoes oxygenation it becomes crimson and then red. When coagulation commences, the yellow colour of the serum shades the red into scarlet, and when allowed to dry up, blood becomes brown. We should avoid a needless difficulty, if without affecting too great precision, we styled living arterial blood, neither crimson nor scarlet, but simply red.

It is scarcely necessary to particularize the cases on record in proof of the insensibility of colour-blind eyes to the difference between red and green by daylight. Dr K. and Dr Y. confound full red, scarlet, and crimson, with various shades of equally full and bright green. The former gentleman, as well as Mr T. and Admiral ——, have independently referred to a red or scarlet cloak, coat, or jacket, as undistinguishable by them, from a hedge or the leaves of a tree. Lord V. thought a lady's green dress scarlet. Mr N.'s brother picked up a red-hot coal as "a green thing." Lady D., Dr E., and Mr Hughes, cannot tell the scarlet berries of the mountain ash from its leaves. Dr Bryce could not distinguish a scarlet geranium from its foliage. Dugald Stewart made the same mistake with the Siberian crab. Dalton held red sealing-wax to match with grass in colour. The tailor's foreman referred to, proposed to sew green tapes to a scarlet waistcoat. Dr Y. could not see a difference between red and green railway signal glasses. And in addition to the cases described in the previous portions of this paper by me, I found in the Edinburgh garrison eleven soldiers, who put side by side as of the same colour, full scarlet and crimson wools, along with full and pale greens, and who identified red with green glass.

A question here arises, much more easily asked than answered—Do colour-blind persons of the class described, see red, but not green; or green, but not red; or do they see both, or neither? This question, or series of questions, will be variously answered, as, so far, it has been by different authorities, and probably demands a different answer in different cases. My own strong conviction, which is at variance with the opinion of some distinguished writers on optics, is, that red and green are *both* visible in favourable circumstances to the majority of the subjects of chromato-pseudopsis.

I am led to this conclusion by two considerations:—1. All the colour-blind persons whose vision I have formally tested, could in favourable circumstances occasionally distinguish red from green; and although always uncertain as to the difference between them, and easily shaken in their conclusion as to which was which, yet practically acted on their judgments, which were not always wrong.

2. I have stated, in reporting Mr Hughes' case (p. 19), that, "When asked to select, from a number of pieces of coloured glass, all the specimens which were red, the majority were rightly chosen, but two or three were green; and in the same way, when assorting greens, he placed a few reds among them." Struck by this fact, I watched narrowly the deportment of the colour-blind soldiers in the Edinburgh garrison, when asked to select reds from greens, and with great uniformity they acted thus:—From a heap of coloured wools, each was asked to select first the red skeins, and then the green, no notice being taken of the selection of individual skeins till eight or nine had been set aside as red, and as many as green. In

all cases the majority of skeins were rightly chosen,—five or six, for example, in the so-called red bundle, were red, and two or three green; and *vice versa* in the so-called green bundle. It is impossible, I think, to avoid the conclusion that, to those who acted thus, the sensation of red, when felt in its full intensity, is distinct from the sensation of green; yet so slight was the difference to their eyes, that they would not unfrequently, on looking at the two bundles, transfer a red skein, as wrongly placed, from the red bundle to the green, or the opposite; and in no case, even when informed that certain of the skeins were in the wrong heap, did they succeed in a just assortment of them. Prolonged contemplation of the colours, indeed, seemed in all cases to make matters worse; and, in general, I have found that the colour-blind, when informed that they have made a mistake in selecting hues, become increasingly uncertain concerning them, and give up for the time attempting to distinguish between them.

It thus appears that red and green are *both* occasionally perceived in daylight by those who more commonly are blind to them, and that the majority of the colour-blind cannot be defined as possessors of "Dichromic Vision," in the strict sense of that term, although it is quite true that they are only *certain* regarding the two primary colours, blue and yellow.

In what has been stated, red and green are referred to as seen by sunlight; but it is a remarkable fact, which has not hitherto been sufficiently regarded, that, by gaslight or candlelight, the distinction between red and green, which to the colour-blind was so slight by daylight, becomes in many cases quite apparent. My attention was first directed to this matter by the statement of Mr N. (p. 29), that by candlelight crimson flowers, such as fuchsias, which by day had been lost among the leaves, stood out in contrast with the foliage, so that it was "*then* quite an enjoyment to look" at them.

On reading this, I recalled the account given of his colour-blindness by Mr D. (p. 14); "the flowers of a scarlet geranium I cannot see distinctly by daylight; but by candlelight there is a marked contrast between them and the leaves."

Without any knowledge of Mr N.'s statement, Prof. Y. repeated (p. 32) his experience in nearly similar words, adding that he "always delighted in going into a conservatory by candlelight, because all the purple and red flowers stood out in such brilliant contrast to the green leaves;" and he further mentions that scarlet flowers then appear brighter than by daylight. Mr R., who proffered the account of his case, stated that,—"Sometimes I can see some reds and greens by lamplight" (p. 27), and in illustration of this mentioned the very striking fact, that a baize curtain which he bought as green by daylight, and which was then agreeable to his eyes, proved excessively painful by lamplight, and turned out to be "a very bright red."

Dr E., in answer to queries, reported his experience to be exactly

similar. Dr Y. whom, by daylight, I had found to make the greatest mistakes between red and green, by gaslight made far fewer blunders (p. 26).

Lastly, Mr S. reports one of the colour-blind persons known to him as being in the practice of resorting to a room lighted with gas or candles, when he wished to tell the difference between scarlet and green, and crimson and blue (p. 34).

On looking over the cases recorded by others, I observe that the better perception of red and green by artificial than by daylight has not escaped the notice of previous writers. Dalton found that to some twenty colour-blind persons, including himself, "*red* and *scarlet* have a more vivid and flaming appearance by candlelight than by daylight;" and that "in all points where we differ from other persons, the difference is much less by candlelight than by daylight."[1] Mr Milne of Edinburgh, also, whose case is described by Mr Combe, "calls crimson blue by day, and bright red by candlelight."

It thus appears that a large number of the colour-blind have discovered that red, still more crimson, and to a less degree than either, scarlet, are distinguishable from green by ordinary artificial light, where they are not distinguishable by daylight. That *both* colours appear different, seems certain from the letters I have printed, and I refer to these because I have had comparatively few opportunities of testing the colour-blind by artificial light. In Dr Y.'s case, however, I know certainly that red or green seen *alone* is distinguished by gaslight where it is mistaken by day; and if each colour is thus altered and rendered more visible by artificial light, the two, seen together, must contrast much more strongly when illuminated by it.

I do not here enter into the explanation of the greater visibility of red and its complementary colour by candle or gas light, which, however, it may be remarked, is chiefly to be sought for in the different quality of this from sunlight; but three points demand notice.

1. The conclusion already insisted on, that red and green are both occasionally visible to the colour-blind who habitually confound them, is greatly strengthened if vision by artificial light be taken into consideration as well as vision by daylight.

2. Those who confuse red and green by daylight continue to do so, though to a less degree, by artificial light.

3. From what is stated above, it follows that, contrary to general belief, our present railway signals are safer, so far as liability to mistake by the colour-blind is concerned, by night than by day. But, as the cases of Mr Hughes and Dr Y. specially illustrate, though safer, they are not safe.

To complete the discussion of red and green in their relation to colour-blindness, two matters call for discussion from their interest in

[1] Mem. Lit. and Phil. Soc., Manchester. 1798. Pp. 40, 41.

connection with the physiology of this affection of vision, and their importance in reference to the observation of colours by the colour-blind.

In describing Dr Bryce's case (p. 20), I have referred to the effect of distance in rendering red invisible to him. His case is not peculiar. Mr D., Mr T., Dr K., Dr E., Admiral ——, all refer to their ceasing to distinguish red from green when removed to a short distance from those colours, although they discriminate them close at hand. My friend Mr David Stevenson, the accomplished engineer of the Northern Lights, has suggested to me that the *distant* colour-blindness referred to may be only the result of ordinary myopia or short-sightedness. That ordinary myopia affects the vision of colours as well as of form or outline is unquestionable, but that there is what may be termed "chromic myopia," or a short-sightedness to colour, not accompanied by a corresponding short-sightedness to form or outline, admits, I believe, of distinct proof. Thus, Dr Bryce described the cruciferous arrangement of the petals of a verbena, but mistook its colour, of which he was reluctant to speak at all. Prof. Y., who is long-sighted, and a practised observer with trigonometrical instruments, states, in reference to the difference between red and green as seen by daylight, that "though I can see them well enough if near, at a little distance the contrast makes no impression on me" (p. 32). Mr T. regards himself as better off than his neighbours, "so far as strength of vision and clear definition both of distant and near objects are concerned," but he adds, that "at a distance of about sixty yards it would puzzle me to distinguish the colour of a soldier's coat, although *the general outline of the figure* would enable me to pronounce upon its being that of a soldier" (p. 30). Admiral —— makes a similar reference to a red jacket and to a tiled barn (p. 31); and Drs K. and E. are equally foiled by red and green objects when removed to a comparatively short distance from them.

From these volunteered statements of sufferers from colour-blindness, I drew the inference that the perception of form and outline remains with their eyes after that of red and green, as accompanying shape, has been lost in consequence of the distance between the spectator and the coloured object being increased; and, conversely, that on walking up to a far off red body, its shape is discerned before its colour. With ordinary myopic eyes, the reverse I believe to be the case. I have appealed to several friends, otherwise normal in vision, who, like myself, are short-sighted, and we agree in the conclusion, that a letter, figure, or device, is visible to us as a shapeless red blot at a distance which precludes us from giving any opinion on its form. At the same time, I have laid Mr Stevenson's suggestion before the more accessible of my colour-blind acquaintances, with the following result:—

Dr K. writes thus:—

"I have your letter relative to the suggestion that the non-per-

ception of red was occasioned by ordinary myopia. I hold this theory to be quite untenable, as many myopic eyes are quite normal as to colour. I am neither annoyed by myopia nor presbyopia. As to outlines of objects, or even minute details of form, whether near or at a distance, I believe my eyesight is at least as acute as that of others; indeed, I should say in this respect, rather more so, from the circumstance that my eye has been trained to look for *difference of form*, seeing I receive little or no aid from that of colour. In the case of red fruits and flowers, I can see the *form* long before I can detect the colour, and this for the simple reason, that the colour of the fruit and leaves being to my eye the same, there is nothing to direct my eye to the point where the fruit is. I have often remarked, that persons with normal eyes remarked to me the existence of fruit on a tree at surprising distances, from the contrast in colour alone; but when I have walked with them towards the tree, and directed them to tell me when they distinctly saw the *form* of each fruit (be it cherry, gean, rowan, or other), I always found that I could see the *form* fully as soon if not sooner than they could, though in my case I was not aided by colour, because fruit and leaves were all one hue to my eye. They saw a blot of red standing out on a mass of green from a great distance, but my eye detected *form* before theirs. I have no doubt on this point relative to my own case."

Dr E. replies, that to the best of his belief he "can see the form of an object long after its colour has been lost to the eye, and to simplify the matter into the shape in which you properly put it, I could tell you whether a spot was round or square, long after I had ceased to recognise colour at all."

To test the matter further, he took a long-sighted, normal-eyed companion with him into a garden, on one of the walls of which a number of crysanthemums were growing in full blossom, visible when first seen from the garden-gate, at a distance of some thirty yards. The flowers were yellow, pink, and crimson. Those which were yellow he saw sooner than his companion, but the red blossoms were imperceptible to him long after they seemed to his friend the most conspicuous objects on the wall.

Further, a fellow-physician made a series of experiments on Dr E.'s perception of colour, by placing wafers, and coloured papers of various shapes at different distances from the eye, with the result which he thus reports:—"The appreciation of *form* was *perfect* (no matter what colour was employed), at any point within the range of *vision*;" whilst so greatly did the appreciation of colour vary with the distance, that a red-purple disc, which was recognised to be such close at hand, was pronounced to be green when removed to a distance; and scarlet and green wafers, which were regarded as showing shades of green or brown close to the eye, were declared to be green at the distance of four feet, and to be pale red at the distance of eight.

Mr Hughes, also, has at my request made observations on the relative visibility at a distance, of form and colour, as displayed in the Royal Scottish Academy's Gallery of Pictures, and reports that he perceives the outlines of painted objects, after he has ceased to be certain regarding their colour. In addition, a medical man, Dr S., whose case I have not recorded, volunteered the statement that he could, though at a considerable distance from them, recognise poppies among green corn, so long as they were unblown, by the marked shape of the drooping unexpanded flower; but as soon as the green calyx was shed, and the scarlet petals were exposed, he lost sight of them.

These cases might suffice; but whilst I write, a party unknown to me, spontaneously sends from Statham, Norwich, a letter on his colour-blindness, in which regarding what he is about to describe, as a peculiarityof his own case, he says :—"I can discern red colours in general, at hand or within a few yards, but fifteen or twenty yards off I cannot distinguish ripe cherries from leaves, although when half-ripe they were quite evident to me."

I feel assured, accordingly, that a colour-blind eye becomes insensitive to red, or doubtful regarding it, at a much shorter distance from a red object than a normal eye does, and ceases to perceive a difference between red and green long before these have become invisible to the perfect eye. In truth, it does not consist, so far as I know, with the familiar experience of those free from colour-blindness, to find that any distance, however great, leads to an identification of red with green; and although what the great anatomist Dr Barclay loved to call *experientia vulgaris* is to be taken with due allowance, yet when we find no normal-eyed person ever hinting at a temptation to mistake a distant red object for a green one, whilst a number of colour-blind persons, who have had no communication with each other, are found acknowledging a prevailing temptation to do this, we cannot hesitate to regard them as blind to red and green at distances which only slightly diminish the contrast between these colours to those possessed of more favoured organs of vision. In support of this conclusion, I would only further refer to two circumstances.

1*st*, A very large number of persons have discovered their colour-blindness by failing to distinguish red flowers or fruits from their leaves unless very near them.

2*d*, Without any reference to the special question under consideration, I have inquired at nearly all the subjects of chromato-pseudopsis known to me what colours they saw in the distant rainbow, and nearly all have replied that they did not see red or green, but saw the other prismatic bands, or at least the yellow and blue. Mr B. (in whom, however, colour-blindness was induced by cerebral injury) sees no colours at all in the rainbow, and does not see red and green close to the eye. But many of those whose cases I have reported distinguish red from green close at hand, yet when they gaze on a rainbow, at a distance from it which does not render them insensible

to two of the three primary colours which it displays, cease to perceive the third primary, red, and also green.

There appears thus to be a "chromic myopia" or short-sightedness to colour, which, so far as I am aware, has not hitherto been generally recognised.

The last point I have to notice in connection with the identification of red with green concerns the dark shades of both colours. The addition of black to red converts it into brown, and a similar addition to green changes it into olive, although that title is more properly applied to a mixture of dark purple and green. The dark-reds and dark-greens thus generated are great puzzles to the colour-blind. Those who confound full bright-red with full bright-green are, I believe, always equally at fault with dark-red and dark-green; and many who do not mistake the pure, fully illuminated colours are stumbled by their darker shades. The particular proof of this will be given in the record of the proportion of persons in the community who err in discriminating colours; but here it is important to notice that not only red-brown (red *plus* black), but orange-brown (orange *plus* black), yellow-brown (yellow *plus* black), and russet, or ruddy-brown (purple *plus* orange), appear to many eyes identical with the darker shades of green. Dr Bryce, Mr Hughes, and Dr C. illustrate this peculiarity of vision. The tailor's foreman (p. 35) has sent among his matches a ruddy-brown and a deep-green. Dr K. and Admiral —— both refer to mistakes in purchasing dresses, which betray the difficulty they encounter in distinguishing brown from green. Mr S. reports his six friends to be very faulty in this respect, and tells of one who purchased a bottle-green coat whilst intending to provide himself with a brown one. A survey, moreover, of all the cases which I have recorded will show that olive, which may be taken to represent all shades of dark-green, and brown in all its shades (but especially russet or red-brown) are for the majority of colour-blind eyes the same or very similar colours.

I dwell upon this point, because an inability to distinguish olive from brown appears to be the slightest manifestation of that well-marked colour-blindness which, when fully developed, ignores the difference between full red and green. This slight colour-blindness is of importance practically, inasmuch as those affected by it not only confound dark shades of the colours in question, but are liable to mistake tints originally bright when these are tarnished by time and exposure, or when they are seen in twilight or dimly illuminated. I have referred, under Dr Bryce's case, to the importance of this slighter colour-blindness in reference to railway signals, and to this I shall recur.

It is important, also, in reference to the physiology of colour-blindness, especially when taken in connection with the chromic myopia already described. Shortened distance or increased darkening, *i. e.*, in both cases, diminished illumination, lessens the sensitiveness of a colour-blind eye to red and green long before it

annihilates the perception of these colours by a normal eye. In this we only see another illustration of that limited range of sensitiveness to colour which has already been referred to as an unenviable prerogative of the colour-blind organ of vision. A slight excess of light is sufficient to paralyse or exhaust its sensitiveness to colour; an equally slight defect of light leaves that sensitiveness unaroused: in both cases colours become invisible.

Confusion of Crimson with Blue.

The confusion of crimson with blue is one of the most characteristic marks of colour-blindness. A reference to the great majority of cases recorded in this paper will show that the subjects of chromato-pseudopsis have independently of each other discovered the peculiarity of their vision in reference to mixtures of red and blue. It will suffice to refer to Dr Y., Prof. Y., Prof. N., and the Countess of D. They have also recognised that the deeper shades of purple, as well as crimson, were liable to appear blue to them, and have separately reached the conclusion that their eyes perceived in mixtures of red and blue only the blue. Prof. Y., for instance, states that, "when blue and red are mixed, the blue is apt to *kill* the red" to his eyes.

Dalton reports of himself, and of the persons, nearly twenty in number, whose colour-vision resembled his own, that crimson appeared to them blue by daylight, and of himself that blue, purple, pink, and crimson seemed to him "all referable to blue."[1]

Apart, therefore, from any hypothesis as to the cause of this limitation of colour-vision, it appears to be one peculiarity of the colour-blind eye to be unable to discern red by daylight, if it be mixed with blue; and a very slight addition of the latter is sufficient to render the former quite invisible, so that a crimson which by many so-called normal eyes is identified with *red*, by colour-blind eyes is identified with *blue*.

By candlelight, as already stated, the tendency to confound red-purple (of which crimson is the reddest shade) with blue disappears, or is greatly lessened, and the experience of a large section of the colour-blind, including Dalton and the cases which he has described, is embodied in the statement of Prof. Y.:—"With purples in daylight the blue overcomes the red; in candlelight, the red either overcomes the blue, or appears in its just proportion, I cannot say which."—P. 32.

Confusion of Red with Black: total invisibility of Red.

By far the most remarkable variety of colour-blindness, in a scientific point of view, is that which shows itself in the identification of red with black. This singular affection of the organ of vision

[1] Manchester Memoirs. 1798. Pp. 28-36.

appears to have escaped the attention of former writers, or to have been at best incidentally noticed in one or two cases as a fact of no particular importance. Yet, the analogy which Sir David Brewster pointed out between the colour-blind eye and the organs of hearing of those to whom Dr Wollaston drew attention as unable, though otherwise free from deafness, to perceive high or shrill notes,[1] a phenomenon which has been made the subject of experiment by later observers, especially Chladni and Savart, might have led to the expectation and detection of an utter blindness to red, which is the obverse (though not the analogue) of deafness to shrill sounds, and to these alone.[2]

Attention was perhaps turned aside from this inquiry by an observation of Dalton's. He accounted for his own colour-blindness by supposing that the *vitreous humour* of his eye was *blue*, and explained his perception of pink, crimson, and red-purple as blue, by the consistent inference, that the red rays which such colours sent to his eyes were stopped or absorbed in their passage through the blue medium, which only transmitted rays of its own hue. But there was a difficulty in the way of this theory, which did not escape its author. "What seemed," observes he, "to make against this opinion, however, was, that I thought red bodies, such as vermilion, should appear black to me, *which was contrary to fact.*"[3] He then proceeds to explain how he disposed of this difficulty, in a passage which need not be discussed, since it was ascertained after Dalton's death that the vitreous humour of his eye was not blue; and, further, singular as it may appear, he did confound (as will presently be shown) certain reds (though not vermilion) with black. Had he been aware of the facts which I am about to record, he would have regarded them as strongly corroborating the truth of his theory. As it was, however, his explicit declaration that he did not see red as black, and that he saw as long a prismatic spectrum as others, has probably led later observers on chromato-pseudopsis to overlook or pay little attention to this form of the affection, although it presents a blindness to colour which may be called absolute.

Scarlet, but still more crimson, and also pure red, are invisible to certain eyes. The following are the principal facts in connection with this invisibility, so far as I have yet ascertained them:—

1. My attention was first strongly directed to the blindness of certain eyes to red, by Mr N. of Torquay's report of his case (p. 29). In his letter he mentions that "a deficiency of daylight makes scarlet resemble black;" that, in evening twilight, "the flowers of a scarlet geranium appear of a velvetty dark gloss,

[1] On Sounds inaudible by certain Ears. Phil. Trans. 1820. P. 306.

[2] According to the undulatory theory, the wave of red light is slower in its vibrations than the other coloured waves. It thus corresponds to the slower undulations of sound, which produce low tones. Blindness to red is, therefore, analogous to deafness to *grave*, not acute sounds.

[3] Mem. Lit. and Phil. Soc., Manch., 1798. P. 42.

much darker than the leaves;" and that, in the same circumstances, he "could not distinguish between a scarlet and a black coat, even when quite close to them." Further, in artificial light, unless it is very strong, "scarlet appears nearly black."

2. Mr T. (p. 30) describes similar peculiarities in his case. A very brilliant scarlet anemone was with difficulty discovered in a bed of flowers, although it was one of the most conspicuous of them, and its position was known; and when at last the eye caught it, it appeared as an ill-defined red blot. Scarlet poppies also, growing amidst corn, constantly eluded Mr T.'s notice. In these cases, and especially the first, the flowers do not seem to have been seen, but it is quite possible that they were not discerned, because they appeared green, and were confounded with the leaves, not because they were altogether invisible. Mr T.'s own impression, however, appears to be that he did not see them at all; and he adds the decisive fact in reference to one object,—"unless close to ripe hawthorn berries I perceived no red, and even when near enough to see the individual berries, they appear to me for the first few seconds rather *black* than *red*, and only gradually assume their red hue." It would thus seem that Mr T.'s eye very tardily responds to the stimulus of red light, so that a red object is first imaged on the retina in black, making for a time no luminous or colorific impression upon it, and only slowly clothing itself with colour.

3. A third example of blindness to red occurred in Mr Hughes (p. 18), who frequently copied red lines in engineering drawings in black. I have since learned from this gentleman that the red which he is thus liable to confound with black is a rather dark shade of crimson.

Greatly struck by those cases, for which I was unprepared by what I had read of colour-blindness, I now made inquiry among the subjects of that peculiarity of vision within my reach as to the relation which appeared to them to subsist between red and black. It soon appeared that a liability to see red as black is by no means uncommon among the colour-blind.

4. Dr E., on being applied to in reference to his experience in the matter, recalled the circumstance of his having written a letter, partly with red, partly with black ink, without being aware of the difference. (P. 21).

5. Dr Y. could not at first recall any occasion on which red had seemed black to him, but he afterwards observed that by gaslight he could distinguish two lettered cards to be respectively red and black, which appeared to him by daylight of the same colour.[1]

[1] In describing Dr Y.'s case (p. 29), I referred to this confusion as having occurred in connection with "the leather binding of church books," but I find that I had misunderstood my informant, who tells me that the coloured objects mistaken, were cards elevated before the congregation in one of the churches of Edinburgh, with numbers referring to tunes upon them, and purposely painted in different colours to indicate which of two music

In addition to those cases, I have discovered several others still more curious, which I now relate.

6. Mr James Inglis, in the establishment of Messrs W. and R. Chambers, informed me of a gentleman in Edinburgh who, on one occasion when walking with him, mistook flakes of dry red paint which had fallen on the pavement for soot. He startled his companion by looking up to the house-tops, remarking that a chimney must have been on fire.

I have had several interviews with the party in question, whom I shall call T. R. He is an educated, intelligent young man, a cautious and conscientious observer, and gave me every facility in examining the peculiarities of his vision.

I found him a strongly marked case of colour-blindness. He again and again arranged, at my request, bundles of coloured wool, as well as coloured papers and glasses, and the detail of one of his arrangements of wools will best show how strongly defined his colour-blindness is.

The table below represents the third assortment of worsteds made at intervals by him. The wools were new, and were left with him for more than a week. He revised the arrangement more than once, and finally sent it as the best he could make. The title of each bundle is the name given to it by the arranger.

BERLIN WOOLS AS ARRANGED BY T. R.

Red Bundle.

3 Scarlets.
1 Crimson (rather dark).
3 Reds (deep).
1 Orange (chrome).
1 Brown (ochre).
2 Greens (rather dark).
1 Citrine (with excess of green).
1 Green (dirty).

Green Bundle.

1 Green (full and bright).
1 Green (full, but bluish).
1 Scarlet (full and bright).
1 Buff (light).
2 Drabs (light).
1 Drab (dark).
1 Flesh-colour (dirty or dull).

Blue Bundle.

2 Blues (bright).
2 Blues (dark).
1 Blue (pale).
1 Purple (dark).
2 Lilacs (1 dark and 1 light).
1 Pink (rose or pale crimson).

Pink Bundle.

1 Salmon colour.
1 Peach blossom.
2 Blues (light).

Brown Bundle.

1 Brown (light ochre).
2 Greens (light).

Orange Bundle.

1 Orange (full and bright).
1 Yellow (dull).
1 Green (pale).
1 Citrine.

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books, both in use, was intended. Dr Y. received no assistance by daylight as to which book should be taken, from the colours of the figures, although each, as I have ascertained, is about three inches long by two broad. The red figures are crimson; the others a blue-black.

Purple Bundle.
2 Crimsons (1 bluer than the other).

Unarranged.
1 Black.
1 Dark Green.

Fawn Bundle.
1 Pale Green.

Yellow Bundle.
1 Pale Yellow.

In the arrangement above, no indications appear of a tendency to confound red with black. The whole of the reds are arranged among positive colours, and the majority are rightly arranged; whilst the solitary black wool is left unplaced, and remains apart, along with a very dark green. In keeping with this exclusion of black from the coloured wools (which, however, was the result of much comparison of them with each other), T. R. could with difficulty recall the fact of his having mistaken red paint for soot, and he had not realized the truth that he was liable to confound red with black. Yet he spontaneously added, on being reminded by his companion of the circumstances attending the mistake in question, that on one occasion seeing a lady in church well known to him, wearing what seemed to him "a *black* bonnet," he asked her for whom she was in mourning, and surprised her greatly by the question, for her bonnet was of *crimson* velvet. He tells me that he has mentally made the same mistake more than once since I first saw him, but warned of his tendency to confound colours, he looked at the apparently black bonnets in different lights, and satisfied himself that they were, or at least might be, red.

Still more recently, he has been discovered by Mr Inglis to be liable to confound red ink with black ink, and I have in my possession a card on which one word is written in crimson, and the other in ordinary ink, both of which appeared to T. R. equally black. The characters are large, and the colours strongly contrast to a normal eye, as they were intended to do by their writer. The card in question, which contained two memoranda for the writer's use, fell accidentally in T. R's way; but to test the matter further, Mr Inglis wrote an entire letter in red ink, which he requested his friend to copy for him. Its colour led to no spontaneous remark on T. R.'s part, and when asked how the ink pleased him, his only comment was, that he thought it rather blue; he had been unaware that the ink was red.

7. This difficulty in distinguishing inks, I believe, is by no means rare. I have made the acquaintance of a clerk in the Edinburgh Post-Office, who has surprised his superiors by signing his name to official papers in red ink. He did this unwittingly, and his customary method of distinguishing red from black ink is by the difference in their respective odours.

I know of two other clerks in town who cannot tell red ink from black ink till it dries, and who also rely upon the difference in odour as a means of distinction between them.

Dr Rowe, of the Royal Asylum, Morningside, informs me

that a friend of his, a banker near London, finding himself constantly confounding red and black ink with each other, had a bottle of a different shape provided for each, as a safeguard against further mistakes. These facts may seem trivial, but they show how comparatively frequent blindness to red is.

8. A case probably as well marked as T. R.'s, occurs in the person of a young clerical student in Glasgow, whom I shall call R. M. T. I have been disappointed in seeing him, but Mr Peter Stevenson, philosophical instrument maker, Edinburgh, who knows him intimately, ascertained the following fact, which is sufficiently decisive in reference to his vision.

He himself and his friends had long been aware that he was to some extent colour-blind, and by way of testing this, he was asked by Mr Stevenson, when recently in Edinburgh, to tell him the colour of a web of children's handkerchiefs hanging at a shop-door, distant in a straight line, about forty feet from the window where he was sitting.

The handkerchiefs in question were white, with rude designs and letters printed on them from copperplates in crimson ink, so that at a little distance they appeared pretty uniformly red. R. M. T. at once pronounced them to be "black like the print of a book;" and as the same designs are as frequently printed in black as red, an eye disposed to confound these colours, and more familiar with the former as occurring in engravings, would be put off its guard by the character of the lettering and designs presented to it. I have seen one of the handkerchiefs, which is of a bright, full crimson colour, but I do not know the peculiarities of R. M. T.'s colour-blindness. He is a student at Glasgow College, and Professor William Thomson has kindly engaged to test his colour-vision by the prismatic solar spectrum, so that further information may be given in the sequel concerning his case.

9. My friend, Mr John Crombie Brown, is acquainted with a party S. N. (known also to Alexander Christie, Esq., A.R.S.A.), who has a fine eye for form and outline, but is markedly colour-blind. In early life he was apprenticed to an upholsterer, and on one occasion being sent for black cloth to cover a coffin, he brought scarlet.

Other cases less fully examined have been reported to me by trustworthy parties.

10. Dr David Skae informs me of a young medical man, formerly an assistant in the Morningside Asylum, who was frequently compelled to appeal to others to decide for him, before sealing a letter, which was red and which black sealing-wax. Mr Walker, the eye-surgeon, also knew this gentleman, and recalls the fact of his mistaking red and black chalks for each other, when engaged in crayon-drawing. He is at present in China, but has been applied to for the particulars of his case.

11. Mr R. S. Grieve, the large carpet-maker, George Street,

Edinburgh, tells me that he has often heard his father speak of a weaver in his employment, who, besides matching red with green, frequently matched scarlet with black.

12. To these cases I may add that of the Countess of D., who enumerates together as colours she cannot confidently pronounce upon, "*red*, green, *black*, brown, and lilac" (p. 37).

After encountering, without specially seeking for them, so many examples of the confusion of red with black, I thought it exceedingly unlikely that previous investigators of colour-blindness should not have met with cases of it; and on searching, it appeared that they had.

Thus Mr Harvey has recorded the case of a tailor in Plymouth who was otherwise colour-blind, and to whom black appeared "generally green, in particular cases crimson." A purplish red flower, the great snap-dragon (*antirrhinum majus*) he pronounced to be *black*, and "a very good match for my [Mr Harvey's] black coat." His master stated, that "being desired to repair an article of dress that required black silk, he employed crimson; and a similar mistake occurred on two other occasions."

"On another occasion, when a young gentleman's dark blue coat was brought to him for immediate repair, the mother was surprised to find the elbow of the coat repaired with crimson." [1] In connection with this last mistake, Mr Harvey quotes a case recorded by Dr Nicholls in the Medico-Chirurgical Transactions, where an officer in the navy "purchased a blue uniform coat and waistcoat, with *red* breeches to match." Here probably, as was the case with Mr Harvey's example, dark blue was undistinguishable from black, and the latter would have been confounded with red also.

Dr Colquhoun of Glasgow has described the case of a gardener in Clydesdale, who was originally a weaver, but gave up that trade, "because he confounded the red, black, green, and purple threads." [2] It is further stated in reference to this person, that "he confounds red with lilac, rose, brown, black, white, although he perceives the difference of the light tints and dark tints;" and that "in bright candlelight he cannot specify the shades of violet or brown, nor those of black, which he takes for brown, red, green, or black." In other respects his case was an extreme one.

I finally turned to Dalton's account of his own case, and that of his fellows, and at first it appeared that he had distinctly ascertained that he did not confound red with black, as I have already illustrated, by a quotation from his paper. Sir John Herschel and Sir David Brewster also, who both paid much attention to Dalton's case, have expressed their conviction that he saw as long a spectrum as others did, but that the red extremity appeared to him yellow. He should, of course, have seen a shorter spectrum than others, had red ap-

[1] Trans. R.S.E., vol. x. 1824, pp. 255–269.

[2] Glasgow Medical Journal, vol. ii. p. 12., 1829, quoted by Wartmann. Scientific Memoirs, 1846, p. 168.

peared black to him; and no one can avoid concurring in the conclusion of the great opticians named above, that Dalton did not *habitually* fail to perceive the less refrangible end of the spectrum, although it did not appear to him red. Herschel, accordingly, in addressing Dalton, says:—"It is clear to me that you, and all others so affected, perceive *as light* every ray which others do. The retina *is excited* by every ray which reaches it." And again,—"It seems to me that we [the normal-eyed] have three primary sensations where you have only two. We refer or can refer in imagination all colours to three,—yellow, red, and blue. All other colours we think we perceive to be mixtures of these, and can produce them by actual mixture of powders of these hues, whereas we cannot produce these by any mixtures of others. . . . . Now, to eyes of your kind, it seems to me that all your tints are referable to two."[1] A similar conviction is stated by Herschel, in his treatise on light in reference to the colour-blind as a class:—"All the prismatic rays have the power of exciting and affecting them with the sensation of *light*, and producing distinct vision, so that the defect arises from no insensibility of the retina to rays of any particular *refrangibility*."[2]

Sir David Brewster thus writes:—"In all those cases [of colour blindness] which have been carefully studied, at least in three of them in which I have had the advantage of making personal observations, namely, those of Mr Troughton, Mr Dalton, and Mr Liston, the eye is capable of seeing the whole of the prismatic spectrum, the red space appearing to be yellow. If the red space consisted of homogeneous or simple red rays, we should be led to infer that the eyes in question were not insensible to red light, but were merely incapable of discriminating between the impressions of red and yellow light. I have lately shown, however, that the prismatic spectrum consists of three equal and coincident spectra of *red*, *yellow*, and *blue* light, and consequently, that much yellow and a small portion of blue light exist in the red space;—and hence it follows that those eyes which see only two colours, viz., *yellow* and *blue*, in the spectrum, are really insensible to the red light of the spectrum, and see only the yellow with the small portion of blue with which the red is mixed. The faintness of the yellow light which is thus seen in the red space, confirms the opinion that the retina has not appreciated the influence of the simple red rays."[3]

A reference to Dalton's own account of the appearance which the solar spectrum presented to his eyes, will show the compatibility of those conclusions with what I have now to urge. Dalton writes thus:—"I found that persons in general distinguish six kinds of

[1] The quotations are from a letter as yet unpublished, but which will appear in the forthcoming life of Dalton, by Dr W. C. Henry, by whom I have been favoured with a perusal of it.

[2] Enclyc. Metrop. Article Light, p. 434.

[3] Letters on Natural Magic. 1832. P. 31.

colour in the solar image, namely, *red*, *orange*, *yellow*, *green*, *blue* and *purple*. Newton, indeed, divides the purple into *indigo* and *violet;* but the difference between him and others is merely nominal. To me it is quite otherwise. I see only *two*, or at most *three*, distinctions. These I should call *yellow* and *blue*, or *yellow*, *blue*, and *purple*. My yellow comprehends the *red*, *orange*, *yellow*, and *green* of others; and my *blue* and *purple* coincide with theirs."[1] Assuredly, this passage appears unhesitatingly to assert, that to its writer the red end of the spectrum appeared yellow; and the fact that Dalton permitted Herschel and Brewster to refer during his lifetime to him as having this impression of the solar image, seems decisive of the matter, especially when it is taken in connection with the fact that the great chemist had anticipated the possibility of red appearing black to him, and had decided by looking at vermilion that it did not so appear. It must be remembered, however, that there is no common language between the colour-blind and the colour-seeing; that Dalton gave in only a silent and negative adhesion to the opinions which I have quoted; and that vermilion, besides that it is not a pure red, is a colour so intense, that although it did not appear black, other reds might. And that other kinds of red than vermilion did appear black to Dalton, is shown by his own account. After the passage which I have quoted, as descriptive of his impression of the spectrum, he continues as follows:—"That part of the image which others call red, appears to me little more than *a shade or defect of light;* after that the orange, yellow, and green seem *one* colour, which descends pretty uniformly from an intense to a rare yellow, making what I should call different shades of yellow."[2] The language here is very precise. The red is not spoken of as appearing yellow, or *any other positive colour;* but as appearing defectively illuminated or dark, *i. e.*, more or less black; whilst the orange, green, and yellow are referred to as different gradations of one positive colour, namely, yellow.

It further appears that, in looking at coloured objects, Dalton was not liable to confound red with yellow, as he certainly should have done if these colours had appeared to his eye identical with each other. Thus, under the head of orange and yellow, as seen both by daylight and candlelight, he writes:—"I do not find that I differ materially from other persons in reference to these colours. I have sometimes seen persons hesitate whether a thing was white or yellow by candlelight, when to me there was no doubt at all."[3] And under red as seen by daylight, he states, as already mentioned, that crimson and pink generally appeared blue, and scarlet was confounded with green.[4]

[1] Mem. Lit. and Phil. Soc. Manchester, 1798. P. 31.
[2] Op. et loc. lit.
[3] Ibid. p. 34.
[4] By artificial light it was otherwise; then crimson and pink became yellowish red or reddish yellow, and red and scarlet appeared much more vivid

Moreover, he tells us,—"All crimsons appear to me to consist chiefly of dark blue; but many of them seem to have a strong tinge of dark brown. I have seen specimens of *crimson*, *claret*, and *mud* which were very nearly alike. Crimson has a *grave* appearance, being the reverse of every showy and splendid colour. Woollen yarn, dyed crimson, or dark blue is the same to me." Again:—"The colour of a florid complexion appears to me that of a dull, opaque, blackish blue upon a white ground. A solution of sulphate of iron in the tincture of galls (that is, dilute black ink) upon white paper, gives a colour much resembling that of a florid complexion. It has no resemblance of the colour of blood." Again:—"Stockings spotted with blood or with dirt would scarcely be distinguishable." Lastly:—"By day some reds are the least showy imaginable; I should call them dark drabs."

It thus appears, that as Dalton saw the red end of the spectrum dark or darkish, so certain red objects showed to his eye as dark blue, dark brown, dark drab, mud-coloured, dirt-coloured, or even like ink. The most famous example of colour-blindness, therefore, should seem, although he did not fully realize the fact himself, to have been in certain circumstances blind to red.

After ascertaining the points which I have mentioned, it became an object of much interest to ascertain whether any of the parties whose cases I have described, would fail to perceive the red end of the spectrum as perfectly as others did. I selected Mr Hughes, Dr Y., Mr B., and T. R. for trial; and Prof. Kelland (to whom I have been under many obligations throughout this inquiry) kindly allowed me the use of the necessary apparatus for the production of the solar spectrum, and assisted in the examination, at which Prof. Robert Hunt and Mr Walker the oculist were also present.

The trials were made on March 4th 1854, and were fewer than we could have wished; but the short period during which sunlight served us, left us no choice but to make a rapid investigation.

A good spectrum was produced on a white paper screen, and the gentlemen under trial were requested, one by one, to describe the colours which they saw in the solar image, and the length to which it extended.

Mr Hughes, who mistakes red for black only when these occur in thin lines, appeared to perceive as long and as many coloured a spectrum as any of us did.

Dr Y., whose judgments on colours are always vacillating and uncertain, was indecisive in his answers, and we did not, as time pressed, make a prolonged examination of his case.

T. R., who is the best marked example known to me, of a strongly marked congenital tendency to confound red with black, was tried both with the spectrum of the sun, and with that of the lime-ball

and superb than by day. In keeping with this, Dalton states, that in the prismatic image of a candle-flame, "the red extremity of the image appears more vivid than that of the solar image."

light. He appeared to see as lengthened a solar spectrum in the direction of the more refrangible rays as any of us did, but at the less refrangible end, when asked by Prof. Kelland to follow his pencil as it was carried from the middle of the spectrum towards the red, and to announce when he ceased to see colour, he invariably arrested the pointer, whilst the red still seemed to our eyes vivid and full. So far as we could judge, from one-sixth to one-eighth of the red was invisible to this gentleman.

The lime-ball spectrum was much fainter and less brilliant than that of the sun, but nearly the whole of the red was not discerned by T. R.

Mr B., it will be remembered, was congenitally perfect in his vision of colours, but became colour-blind after a severe accident which occasioned concussion of the brain. (*Ante* p. 39). Bright blue and yellow are the only colours which he distinctly perceives, and these only close at hand; but he is not aware of any special tendency to confound red with black.

He saw a much shorter solar spectrum than any one else, the blue and the red ends being both truncated, and two colours only, yellow and blue, being recognised. He was tried with the prismatic image in various directions, and at successive intervals, but he always gave the same answer, pronouncing fully one-third of the red extremity to be undistinguishable to him from those portions of the sheet of paper on which the spectrum did not fall. A faint, stray light accidentally cast upon the paper was plainly distinguishable to him from the surrounding darkish space, but the extreme red, which, to the eyes of Prof. Kelland, Prof. Hunt, Mr Walker, and myself, was very vivid, was to him invisible. When requested to look at the solar spectrum through a cobalt-blue glass, which, to normal eyes, cuts off a portion of the red, but not the extreme red, he lost the red altogether.

The lime-ball spectrum, when looked at by Mr B. with the naked eye, was in the same way invisible at its less refrangible extremity, and what seemed to us a clearly defined red, conveyed no sensation of either light or colour to his eyes.

Although the examination I have reported was more hurried than was desirable, no doubt remained on our minds, that a portion of the spectral red, both of the sun's light, and of that of incandescent lime was invisible to T. R. and to Mr B.; and further, that the missing red was not replaced by yellow or any other colour, or by a colourless luminous impression, but so far as could be ascertained in a room not absolutely dark, was exchanged for black, or at least a deep grey.

Altogether, then, the proof of blindness to red, as a peculiarity of the colour-blind eye, is, I think, complete, but I wish to guard against being supposed to refer to it as constant in those in whom it occurs. On the other hand, it is only occasional, and the conditions of its occurrence are as yet imperfectly known. The modifications

which Savart's researches have compelled us to make on Wollaston's conclusions regarding *shrill deafness* warn me against affirming that there are no circumstances in which T. R., Mr B., or others like them, would see the whole red of the spectrum. A prismatic image of great intensity of colour might be visible throughout its entire length, where a feebler spectrum was only partially visible; and the concentration of the red rays by a lens might enable them to produce their normal impression on the most markedly colour-blind eye.

I have been slow to publish the results which are announced in this section, from their incompatibility with the conclusions of Sir John Herschel and Sir David Brewster, who regard the colour-blind as perceiving as long a spectrum as the normal-eyed do. It is not my object, however, to affirm that to every colour-blind eye the spectrum is, in all circumstances, shorter than to every normal one, or that the same eye, whether normal or not, always sees a spectrum of the same length. The opposite is as likely to be the truth; and it may be expected that future inquiry will show that my inferences are reconcilable with those at least of the first-named philosopher.

The views of Sir David Brewster on colour-blindness, as known to me from his "Letters on Natural Magic," which I believed to contain his fullest views on the subject, are not so easily reconciled with my results; for, in accordance with his beautiful doctrine of a triple spectrum, he urges that an eye blind to red, but perceptive of yellow and blue, must continue to see these, and especially yellow, in the less refrangible end of the spectrum, and as each of the three-coloured spectra is equally long, the absence of one of the three (namely, the red), though it altered the colour, could not alter the length of the residual two-coloured image.

Since reducing my results to writing, however, I have found a fuller statement of Brewster's views, which not only accords in many respects with the conclusions I have reached, but anticipates certain of them. Apart, accordingly, from the interesting nature of his speculations, it is an act of simple justice to point out where he has anticipated me. His later views are contained in a paper entitled, "Observations on Colour-blindness, or Insensibility to the Impressions of Certain Colours."[1]

After a reference to Wollaston's observations on deafness to shrill notes, he proceeds:—"I have proved from numerous experiments, that when the retina is rendered partially insensible by the action of light upon any one part of it, *it first becomes insensible to red light;* and hence we have a distinct reason why *red-colour blindness* is the

[1] Phil. Mag., August 1844, p. 134. This paper is referred to in the notes added to the translation of Wartmann's paper "On Daltonism," in Taylor's Scientific Memoirs for 1846, by the editor of that work. Its title, however, is not given, nor are the opinions of Brewster, quoted above, noticed by the editor, whose quotations and references led me to suppose that it was simply a correction by Sir David (as in part it is) of certain misapprehensions of his views by Prof. Wartmann, so that I did not consult it till quite recently.

general character of the defect under consideration; and I am persuaded that any defect of sensibility produced by the action of light, or by any other cause, will, if carefully examined, be found to be a maximum with *red* light.

"In experiments of this kind, in which what we may call *artificial colour-blindness* is produced, the intensity of the light is always diminished; but it remains to be determined by accurate observation whether the *red* end of the spectrum (for example), when seen *yellow* by an eye defective in its judgment of colours, is *brighter* or more *obscure* than it would have been had no such defect existed. I am persuaded, from many observations I have made, though I do not consider them as decisive of the question, that the object is seen more obscure, and that certain of the rays emanating from it are not appreciated by the nervous membrane. If, on the other hand, every ray from the red object is efficacious, and the only effect is the substitution of *yellow* or *green* in place of *red*, then we might expect that the object would appear brighter, in so far as a *yellow* sensation produced by a given number of red rays should be brighter than a *red* sensation produced by the same number." [1]

In another part of the paper this view is again referred to:— "According to the doctrine of the triple spectrum, the red space consists of *red*, *yellow*, and *blue* light, the *red* predominating, and the *blue* being extremely feeble. Now, the late Mr Troughton, whose colour-blindness was examined by Sir John Herschel and myself, on separate occasions, saw this *red space, yellow*. Hence, according to my views, he saw a space containing much *yellow* and little *blue*, the *red* light being, as it were, absorbed, in consequence of the nervous membrane being insensible to its action. If this be the case, there must have been a diminution of light in the red space seen by Mr Troughton, and I am persuaded, from the experiments I made upon his eyes (he confounded with green leaves red petals which were far more luminous than the leaves), that this was the case; but whether it was to the extent of the total defalcation of the red rays I will not venture to assert. But it is not necessary that it should be so; *the defective perception of red light may be accompanied with a more acute perception of the other colours*, in a manner analogous to what takes place in the chemical spectrum, where the removal of the red rays produces an increased action of the rays which are left." [2]

From these important observations it will be seen that Sir David Brewster has satisfied himself that a normal eye loses sensibility sooner to red light than to that of any other colour; that an eye defective from any cause in sensibility to light, will show its defect most when tested by red light; and that, in one well marked case of colour-blindness, red bodies appeared less luminous than others which were in reality darker. These observations are quite in accordance with the total insensibility of red, to which I have drawn attention

[1] Op. Cit. p. 136.

[2] Ibid. p. 139.

in this section, and the confusion of red petals with green leaves, to which the author has referred, as proving the obscurity of red to Mr Troughton's eyes, is so nearly universal among the colour-blind, that I may thus far adduce Sir David as at one with me in regarding red as appearing dark or darkish when seen by them.

He holds, however, also, it will be seen, the remarkable opinion that the red light of the spectrum may appear much brighter, instead of much darker, to a colour-blind eye than to a normal one, in consequence of the former not perceiving the red, but instead thereof, yellow light of the same refrangibility, which makes a much stronger impression upon the retina.

Additional observations can alone determine whether the anticipated phenomenon ever occurs. Its occurrence, however, would not be at variance with the appearance of red or crimson bodies as black to a colour-blind eye, as they do not transmit or reflect yellow rays to affect the retina. It is otherwise with scarlet bodies, which should appear as bright yellow to eyes which simply ignored red. But it is with green, not with yellow, that scarlet is systematically confounded by the colour-blind, as a review of all the recorded cases will fully demonstrate, and the green thus identified with scarlet is not a pale or yellowish green, but a full, and often dark, shade of that colour. Thus, Dalton compared sealing wax to one side of a laurel leaf, and a red wafer to the other, and his doctor's scarlet gown to the leaves of trees; nor was his case in this respect peculiar, for the colour-blind are constantly found unable to distinguish the petals of the scarlet geranium from its leaves, the flowers of the wild poppy from the unripe corn amongst which it is growing, and the holly berry and rowan (or mountain-ash) berry, from their foliage. Moreover, those who thus mistake scarlet, regard green as a darkish colour, and confound it with drab.

From these facts, coupled with the observed invisibility of red, I cannot avoid inferring that a colour-blind eye does not simply ignore red in a compound colour, or receive no impression from it, when it looks at scarlet, but that it sees the *red* as *black;* and I suggest that it is the mingled sensation of this black with the accompanying yellow, that causes scarlet, and even orange, to appear a drab-like green.

A similar phenomenon appears in connection with mixtures of red and blue. It is eminently characteristic of the colour-blind (as has been abundantly shown) to mistake such mixtures in all their shades from pink and crimson, to violet and purple, for blue. It perplexed me long in examining such cases to find that even the redder crimsons and the paler shades of these, such as occur in the lips, and in the petals of the fuchsia, in the rose, and the pink, were spoken of by the colour-blind, in such decided terms as appearing blue to them, that I could not help inferring that they received the impression of a much deeper blue than normal eyes would have obtained from purples, or red-blues, simply deprived of their red.

Since, however, I have observed the total invisibility of red, I

have inferred that the colour-blind do not see a red-blue as blue *minus* red, but as blue *minus* red *plus* black; in other words, the red is not merely abolished, but is replaced by black, and the reddest purple must, in such circumstances, appear a very dark blue.

I am thus inclined to regard the confusion of scarlet with green and of purple with blue, as phenomena of the same nature, and depending upon the same cause as the confusion of red with black, from which they differ only in degree. I do not, accordingly, anticipate that the colour-blind will generally be found to see the red end of the solar spectrum brighter than others do, but the reverse; although it would be unwise to dogmatise on the peculiarities which may be found in detached cases of colour-blindness.

I have further to mention, that since reaching these conclusions, I find that Prof. Dove has drawn attention to certain phenomena connected with the normal vision of red, which are important from the light they throw upon the subject before us.[1]

Dove has frequently observed that on leaving a picture-gallery at the approach of night, a parting glance showed that "the red colour had altogether disappeared, while the blue appeared in all its strength. Artists," it is added, "are well aware of this fact." This is a phenomenon presented to the normal eye, plainly differing, only in degree, from that observed by the fox-hunter, who, as already mentioned, in dim twilight, lost the power of distinguishing a scarlet from a black coat.

The longer visibility of blue than of red in faint light, Dove has shown, may be rendered manifest by looking at a stereoscopic combination, the halves of which are drawn in white on a black ground, through coloured glass.

If the one eye gazes through a red glass, and the other through a blue one, the red lines are the most vivid whilst daylight is intense, but, "as the twilight advances, the red becomes weaker and weaker; it finally disappears altogether, and instead of the relief formed by the combination of the red and blue outlines, the blue alone is observed as projection. . . . . If two red glasses be now placed before the openings of the stereoscope, nothing whatever is seen; while with two blue glasses [even though ten times thicker than the red glass], the relief appears in blue lines, and remains distinctly visible for a quarter of an hour longer. Thus, the fact of the earlier disappearance of the red rays is placed beyond a doubt."[2]

It thus appears from the general experience of painters, and from the special trials of Brewster and Dove, that we all become sooner blind to red than to other colours, so that between us and the colour-blind, emphatically so-called, there is but a difference in degree, and they may with perfect justice insist upon applying also to us the name which we have devised for them.

[1] On the Stereoscopic Combination of Colours, etc. By H. W. Dove. Translated in abstract by Dr J. H. Tyndall. Phil. Mag., Oct. 1852, p. 241.
[2] Op. Cit. p. 247.

IV.—EXTENT TO WHICH COLOUR-BLINDNESS PREVAILS IN MALES AND FEMALES.

No formal statistical inquiry embracing a considerable number of individuals has hitherto been instituted into the extent of colour-blindness among the community of any country, and the few limited inquiries which have been made have referred almost entirely to persons of the male sex. The results, however, which have been reached are sufficiently important to demand discussion here.

The first who made any attempt to ascertain the number of colour-blind in the population was Dalton. Besides tracing out among his acquaintances some twenty cases, he observes, "it is remarkable that, out of 25 pupils I once had, to whom I explained this subject, 2 were found to agree with me; and on another similar occasion 1."[1] Adding Dalton to his pupils, we shall have in the first case 3 in 26, or nearly 12 per cent. colour-blind, and in the second 2 in 26, or nearly 8 per cent. These are very high proportions, and the parties, according to Dalton's statement, presented colour-blindness in its most marked form.

Professor Pierre Prevost is referred to by Wartmann[2] as having estimated the colour-blind as amounting to 1 in 20, or 5 per cent., but it is not stated how many persons he examined, or what their kind of colour-blindness was. Professor Seebeck "found 5 out of 40 youths who composed the two upper classes in a gymnasium at Berlin" the subjects of colour-blindness.[3] The proportion here given is higher than Dalton's highest number, exceeding 12 per cent., but the degree of colour-blindness is not stated, and from Seebeck's classification, as given by Wartmann, it is not probable that all the cases were so marked as those included in the English philosopher's list.

Professor Kelland, of the University of Edinburgh, informs me, that among 150 students attending his mathematical classes during the winter session of 1852–53, he found 3 who could not distinguish red from green. In his own words, they were "thorough Daltonians," and there were several less marked cases which were not included in the numeration.

In the same winter I found among about 20 of my students 2 cases (Mr P. and Mr D.), which will be seen from the record of them, to have been of the most marked kind. On the other hand, among 47 students of the Edinburgh Veterinary College, only one unimportant case occurred, of a party who confounded green with blue.

Among the Edinburgh police, 158 of whom were examined last winter by my friend, Mr Finlay Dun,[4] Lecturer on Materia Medica to the Edinburgh Veterinary College, 5 cases were encountered.

[1] Manchester Mem., 1798, p. 39.

[2] Taylor's Scientific Mem., 1846, p. 171.

[3] Op. et loc. cit.

[4] To this gentleman I am under very great obligations for his willing and efficient assistance in collecting the statistics given in this section.

One of these confounded full red and green, 2 confounded brown and dark green, and 1 blue and green.

Dr Rowe, of the Royal Asylum for the Insane, Morningside, kindly tested the colour-vision of the male attendants in that institution, and found among 42, 5 colour-blind. Of these, 2 were very decided examples of the confusion of red with green; 1 mistook brown for green, and 2 blue for green.[1]

Anxious to extend the inquiry to a larger number of persons, I obtained permission from the commanding officers of the cavalry, infantry, and artillery detachments in Edinburgh and Leith, to examine the vision of their men, and the results obtained were, in several respects, important. Every facility was afforded by the military authorities, to whom I have here to express my great obligations for the service rendered me.

The investigation was made by daylight, in the latter part of October 1853; and as the scanty leisure accorded to a soldier in a short winter day could not be largely encroached upon, it was impossible, though some hours were devoted daily by Mr Dun and myself, for nearly a fortnight, to the inquiry, to make other than a rapid examination of each individual. Accordingly, as I was mainly anxious to ascertain how far the prevalence of colour-blindness in the community rendered the red and green signals in use on our railways unsafe, I confined my observations almost entirely to the difficulties attending the discrimination of red from green, and brown from green; mistakes between other colours being noticed only when they prominently presented themselves; though even then they were not always recorded.

The men were examined one by one; in the first place by asking them to name coloured papers, or the diagrams in Mr D. R. Hay's Nomenclature of Colours. Their catalogue of names, unless they had previously followed trades conversant with colours, was in all cases exceedingly scanty, including in general only the terms red, blue, yellow, green, and brown (which last, however, was often wanting); purple being scarcely ever named, and orange, I may say, never. By requesting them, however, to refer the colours shown them to red, blue, or yellow, all necessity for precise terms, in the case of compound tints, was dispensed with, and the risk was avoided, of confounding those who could not name colours, with those who could not distinguish them.

The majority answered promptly in reference to red, blue, and yellow; purple was generally called either blue or brown, but was nevertheless distinguished from these colours, when shown side by side with them; orange was almost invariably called red, and there was great uncertainty as to the difference between green and blue. Those who gave reasonably intelligent answers in reference to the

[1] It was not thought advisable to include in the examination the patients of the Asylum, as the amount of reliance to be placed on their answers could not be determined.

names of the primary and secondary colours, were dismissed without further inquiry; but if any marked hesitation was shown in distinguishing red from green or brown, they were asked without naming them to assort coloured papers, wools, and pieces of glass, and to place those of the same hue together.

Proceeding in this way, 31 colour-blind persons were found among 437 soldiers of the 4th or King's Own Infantry. Of these, 5 confounded full red with full green, and 1 pink with light green; 13 confounded brown with green, and 12 blue with green.

Among 177 soldiers of the 7th Hussars, 14 were colour-blind; 4 mistaking full red for full green, and 1 pink for light green; 2 brown for green, 6 blue for green, and 1 yellow for pink.

Of the detachment of artillery at Leith Fort, 123 were examined, 5 of whom were distinct cases of colour-blindness, and 2 were doubtful. Of these, 2 mistook full red and green, 1 brown and green, 2 blue and green, and 2 whose cases have already been referred to (*ante*, p. 44), appeared to mistake purple and yellow.

The list thus given errs by defect, not excess, especially in reference to the confusion of red with green. In so rapid an inquiry as I was under the necessity of making, only the more prominent cases could be detected, and timorous, sulky, obstinate, or unwilling witnesses had frequently to be dismissed, though their cases were suspicious, rather than prolong the detention of a company or troop of their fellow-soldiers, who were waiting to be examined man by man Those, however, who distinctly betrayed a tendency to confound red or brown with green, were very carefully examined by Mr Dun and myself together, and the attention of the officers present was directed to the mistakes made, so as to secure us against any attempt at deceit on the part of the men.[1]

The results obtained in Edinburgh in 1852–53 are given in the following table, the two doubtful cases of confusion of yellow and purple occurring among the artillerymen being omitted, as well as the one of yellow and pink among the Hussars; whilst the case of pink and light green among the latter, and the similar case among the infantry, are classified along with red and green.

Each person is put down under a single head, but it is to be observed that those who confounded red with green, also confounded brown with green, and were uncertain as to the difference between blue and green. I have no doubt, also, that several of those who appear only as hesitating between brown and green, were liable to mistake red for the latter colour. Two of the Hussars classified under "red and green" were brothers. None of the other parties, so far as I know, were relatives.

[1] In one case only, I was cautioned, in his hearing, by a sergeant of his company, against crediting the statements of a soldier, as alike unwilling and unable to speak the truth; and although a subsequent private examination led me to believe that he was a *bona fide* case of colour-blindness, the man was so ignorant and eccentric, that I thought it best to exclude him from my list.

It is further of importance to notice, that although the observations were made at Edinburgh, exceedingly few of the persons examined were born in that city, and very few are settled in it. The soldiers, who form more than half the number referred to in the table, were chiefly from England and Ireland, a few being from Scotland and Wales. The students of the mathematical classes of the University, my own pupils, and those of the Veterinary College, are mainly gathered from the various districts of Scotland, and to a smaller extent from England, Ireland, and Wales. The police are recruited from all quarters, and I believe the same may be said of the attendants in the Morningside Asylum; at all events, the most marked cases of colour-blindness among them, are presented by persons who have come from a distance to Edinburgh. Altogether, then, the parties whose cases are reported represent fairly, though unequally, all the sections of our population.

If to the numbers given in the accompanying table, those obtained by Dalton, Prevost, and Seebeck, be added, the extent to which colour-blindness prevails will appear more markedly; but I omit them, because Dalton's numbers apply to 1793–94,[1] and the cases enumerated by the other observers are not classified. How far any of the results are applicable to the entire community, I shall not attempt to decide; but the number of cases of colour-blindness which have been discovered by every one who has sought for them, shows that the general per-centage cannot be very low. Only two of the cases (Mr P. and Mr D.) enumerated in the table, are described by me in this paper; I have left many known to me undescribed, whilst fresh examples are continually presenting themselves. The experience of Professor Kelland, and Professor Allen Thomson, as to the comparative frequency of colour-blindness, has been similar; M. D'Hombre-Firmas has met with corresponding results in France;[2] and I learn from a gentleman recently returned from Germany, that Professor Dove, in some lectures lately delivered in Berlin on colour-blindness, referred to the unexpectedly large number of persons he had found subject to this peculiarity of vision, although experienced oculists in large practice had never heard of a case.

Further: no fact is better ascertained than that colour-blindness clings to certain families, and is hereditary. With few exceptions, every one of the parties whose cases I have specially recorded in this paper, has near relatives as colour-blind as himself. Thus, Dalton had a brother, and so have Professor L. (whose case I have not described), Dr S., Mr N., and Dr Y., circumstanced like themselves in the matter of vision. Mr X. (whose case, however, is not described), introduced to me by Professor Bennett of Edinburgh,

[1] Dalton himself lived till 1844, continuing to the end of his days as decidedly colour-blind as he was when he first detected his peculiarity of vision.

[2] Liebig and Kopp's Annual Report, 1853, p. 131.

EXTENT OF COLOUR-BLINDNESS, AS ASCERTAINED BY THE EXAMINATION OF 1154 PERSONS AT EDINBURGH, IN 1852–53.

Profession.	Number of Persons Examined.	Confounded Red with Green.	Confounded Brown with Green.	Confounded Blue with Green.	No. of Persons Colour-Blind.	Per Centage of Persons Colour-Blind.	Proportion of Persons Colour-Blind as referred to Unity.
4th Infantry, . . .	437	6	13	12	31	7·1	1 in 14·1
7th Hussars, . . .	177	5	2	6	13	7·3	1 in 13·6
Artillery Soldiers, Leith Fort,	123	2	1	2	5	4·0	1 in 24·6
Professor Kelland's Pupils, Edinburgh University, .	150	3	0	0	3	2	1 in 50
Edinburgh Police, . .	158	1	2	2	5	3·1	1 in 31·6
Students of the Edinburgh Veterinary College, .	47	0	0	1	1	2·1	1 in 47
Medical and other attendants, Royal Asylum, Morningside, . . .	42	2	1	2	5	11·9	1 in 8·4
Dr G. Wilson's Pupils, .	20	2	0	0	2	10·0	1 in 10
	1154	21	19	25	65	Average 5·6	Average 1 in 17·7

RATIO OF SPECIAL COLOUR-BLINDNESS, AS DEDUCED FROM PREVIOUS TABLE.

Confound Red with Green, 1·8 per cent., or 1 in 55 ; confound Brown with Green, 1·6 per cent., or 1 in 60 ; confound Blue with Green, 2·2 per cent., or 1 in 46.

has five brothers as defective in vision as himself. Mr D.'s father, brother, sister, and nephew, are colour-blind; the Countess of D.'s father, a son, and two nephews, see colours as she does; and Mr S. of London has, or had, five near relatives sharing with him in marked colour-blindness. It seems, indeed, a safe estimate, that every decided case of colour-blindness implies the existence of another case of equal or similar severity in the person of a relative, so that the numbers I have given as representing the proportion of colour-blindness in the community, may fairly be doubled.

For my own part, accordingly, I think it probable that the number of persons in this country as markedly colour-blind as Dalton was, *i.e.*, given to mistake red for green, brown for green, purple for blue, and occasionally even red for black, is not less than 1 in 50; and including all kinds and degrees of colour-blindness, 1 in 20. At all events, the prevalence of this peculiarity of vision is certainly such as to make it an object of interest and importance to the entire community.

In the table above, the number of colour-blind is estimated on the assumption that they are uniformly distributed throughout the community. Such an assumption must be made before any per-centage table of statistics can be constructed, and for many purposes it is a useful fiction. But after, in the case under consideration, it has served the important purpose of showing how prevalent colour-blindness is, it must be set aside, whilst we ask the question, not less important, "In what proportion are the colour-blind divided amongst the population?"

Statisticians have made very few attempts to answer such a question, in reference to the idiosyncracies or diseases which they have discussed and tabulated; doubtless because, however important they may deem such queries, they have found it impossible to give replies of almost any value to them. The law regulating the mode in which the totally blind, the deaf, or the like, are distributed throughout the community, must be one very difficult to discover; and it may be questioned whether the discovery would yield a result worth the trouble of attaining it. But in the matter of colour-blindness, considered in connection with the use of coloured signals on railways and at sea, it is scarcely more important to know what the per-centage of cases is, than it is to learn to what extent these are concentrated in particular localities, and of more sparing occurrence in others. The hereditary character of colour-blindness, must of necessity keep it running in certain lines of descent, and preponderating in certain families. An instance of this, pertinent to the point, is presented by the 7th Hussars, two of the most marked cases among whom are brothers.

Apart, however, from relationship, as affecting the distribution throughout the community of the colour-blind, it will be seen from the table that their allotment among the population is, as might have been anticipated, *apparently* most capricious. And hopeless as it is, in our present state of knowledge, to resolve this seeming

caprice into the rigid law which doubtless underlies it, one conclusion of very great importance is plainly deducible from the cases recorded, namely, that whilst the average proportion of examples of colour-blindness is high, the extent to which these may become concentrated in single spots is also very remarkable.

This will appear from the following table, in which the results already given are stated more fully, along with certain additional particulars referring, however, solely to the confusion of red and brown with green.[1]

DISTRIBUTION OF THE COLOUR-BLIND AMONG 1058 PERSONS.

Profession.	No. of Individuals.	Confound Red and Green.	Confound Brown and Green.
Professor Kelland's Students, meeting daily together for 5½ months, . . .	150	3	0
Edinburgh Police on duty together, ...	158	1	2
Dr G. Wilson's Students, meeting daily together for 5½ months, . . .	20	2	0
4th Infantry, Edinburgh Castle.			
a. *Two Companies,* . .	91	1	1
b. *Two Companies,* . .	88	2	4
c. *Two Companies,* . .	86	1	5
d. *Two Companies,* . .	110	2	3
Artillery, Leith Fort.			
a. *Detachment, first day,* .	64	2	0
b. *Detachment, second day,*	59	0	1
7th Hussars, Piershill.			
a. *One Troop, including* 2 *Officers,* . . .	47	2	
b. *One Troop,* . . .	81	2	
c. *One Troop,* . . .	49	1	2
a. Dalton and his Pupils on one occasion, . . .	26	3	0
b. Dalton and other Pupils on a different occasion, .	26	2	0
Resident Medical Officers of a Public Institution, acting together for several years,	3	2	0

[1] The wording of Dalton's statement regarding his second set of pupils included in the table is rather obscure. I have interpreted it as signifying that

In the table above (p. 74) the same parties are not counted twice, except of course, Dalton, along with his two sets of pupils. Among the cavalry and infantry soldiers, one or two officers' servants, and musicians of the band, are included; and the artillery were taken as they presented themselves on the two days devoted to their examination. Upon the whole, however, each section of persons represents a set of individuals acting for weeks, months, or even years together, as the staff of officials on a line of railway, or the seamen of a ship, who are constantly using coloured signals, are called to do. The evils which might arise in the employment or observation of such signals, by bodies of men containing so many persons unable to distinguish the colours preferred in signalling, will be referred to in the concluding section of the paper. Here I wish simply to present the statistics of colour-blindness apart from any consideration as to the conclusions they warrant.

I have no results, it will be seen, to offer respecting the prevalence of colour-blindness among females. I have already stated my conviction that it is rarer among them than among males, but only an extended inquiry can show the amount of the difference in this respect between the sexes.

Opportunities do not largely offer themselves in Edinburgh for testing the colour-vision of an associated number of females, unless in the Charity Schools, where the girls are too young, and, comparatively speaking, too uneducated, to make their examination satisfactory. I commend the inquiry to the teachers of the Schools of Design, and the drawing-masters of educational institutions for ladies, who have it in their power, without putting formal queries, to ascertain with great precision the power of discriminating colours possessed by their female pupils. The surgeons, also, of the large cotton mills or factories could, without much difficulty, examine the bands of female workers under their charge. Their age would atone for any defect in their education, especially in those cases where their avocations led to their dealing with colours.

Reverting, in conclusion, to the colour-blindness of males, it is worth a moment's consideration how far this peculiarity of vision characterises one race of men more than another. It is, doubtless, more common among the civilised nations, large numbers of whom are doomed, by that division of labour, which is a great source of their strength, to occupations which dwarf one or more of the external senses, than it is among the uncivilised races, each member of whom cares only to do what is "right in his own eyes," and cultivates the powers of those eyes to the fullest.

Among both the civilised and uncivilised nations, however, there

on both the occasions he alludes to, his pupils were 25, or thereabouts, in number: if his words do not bear this interpretation, it is as probable that they refer to a smaller as to a larger number, for he was not over-burdened with students in his early days.

are doubtless great differences in original endowment, so far as the sense of colour is concerned; and, as may be reasonably surmised, there are corresponding differences in the extent to which colour-blindness prevails among them. Thus, those eastern and southern nations, who live under bright skies, among plants and animals of vivid and brilliant colours, exhibit—partly as a prerogative of race, partly and largely as an effect of such colours daily impressing them—a delight and skill in arranging, matching, and harmonising tints, such as are incompatible with colour-blindness, and imply its rare occurrence in those whose love of colour and command over it are so great.

The Chinese, the Japanese, many of the tribes of Hindostan, the Venetians, the Italians, the Spaniards, the Flemings, the inhabitants of Southern France, and some of the northern Teutonic and Celtic tribes have, as florists, painters, dyers, weavers, glass and porcelain makers and stainers, excelled for centuries sister-nations in the management of colours. Among untutored races, the Indians of the American continent, the African tribes, the uncivilised races of Central and Southern Asia, and the inhabitants of the islands in the Pacific Ocean, have shown by their war-paint, their crowns of brilliant flowers, and still more brilliant birds' feathers, their brightly stained skins and parti-coloured dresses, their dedication of the most splendid coloured objects to their gods and their chiefs, besides much else; that however different their canons of taste may be, they are as passionate and exclusive lovers of colour, as the over-civilised ancient nations who allowed none but princes to wear robes dipped in the Tyrian dye, or to write with purple ink.

On the other hand, the civilised nations of temperate climes, where the summers are short and the winters long and gloomy, living under sombre skies, amidst a Fauna and Flora of pallid and inconspicuous, or dark and subdued tints, and surrounded by masses of green which satisfy, but do not excite the eye, care little for brilliant colours in their dress or household adornments, compared with the inhabitants of more sunny regions; and probably are more liable to colour-blindness than they.

A similar observation may probably be made, with the deductions requisite in contrasting the condition of the external senses in civilised and uncivilised nations, in reference to such races as the Esquimaux and Fuegians, and especially to the former, who live in regions bereft of vegetation during the greater portion of the year, and presenting to the eye little but the dazzling monotony of ice and snow. The sense of colour must, to a great extent, lie dormant in those so circumstanced, and become dulled through want of exercise. The tribes in question and others in similar latitudes seem very indifferent to colour, as an addition to their dress or ornaments.

The examination of single individuals of a nation, can, of course, settle nothing concerning the endowments of the whole people; but I may mention here, as at least interesting in itself, that through the

kindness of the parties themselves, who took a hearty interest in the subject of colour-blindness, I have had the opportunity of testing the colour-vision of Wong Fun, the Chinese student of medicine; of Tiyo Soga, a Caffre student of the United Presbyterian Church; and of the five Turco-Egyptian gentlemen who are prosecuting medicine and physics in Edinburgh at present. Their appreciation of colour is excellent, and certainly superior to that of the majority of our own students, who have not accidentally or designedly made colour a special object of study. The most expert of them all was the young Caffre, an amiable, gentle, intelligent person, who named the colours shown him with great rapidity and precision, although his English vocabulary of colour-names was necessarily limited, and matched Berlin wools and tinted papers with a readiness and unhesitatingness, such as even practised professional colourists might envy.

V.—THEORIES OF COLOUR-BLINDNESS.

The seat or cause of colour-blindness probably lies altogether beyond our reach; but whatever we can learn concerning it, is certain to be of service in determining the extent to which we may hope to cure or alleviate this affection of vision.

Amidst many minor diversities there are but two prominent physical theories of colour-blindness.

The one of these refers the false perception of colours to the *chromatic condition* of certain portions of the optical apparatus of the eye; the other to the *peculiar organization of its nervous apparatus*, including so much of the brain as is essential to vision. This latter view is now nearly universally adopted, although it is necessarily greatly modified in its mode of statement by the metaphysical or psychological views of those who embrace it.

Chromatic Theory.

The first, or CHROMATIC THEORY (as it may be named), of colour-blindness, has been proposed under one form by Dalton, and under another by Brewster. Both are ingenious and interesting speculations; after considering which I shall offer some suggestions of my own, in connection with a chromatic theory differing from either.

Dalton was not convinced of the peculiarity of his own vision, although he had suspected it before, till, as he tells us, "I accidentally observed the colour of the flower of the *geranium zonale* by candlelight, in the autumn of 1792. The flower was pink, but it appeared to me almost an exact sky-blue by day; in candlelight, however, it was astonishingly changed, not having then any blue in it, but being what I called red, a colour which forms a striking contrast to blue."[1]

[1] Manchester Mem., 1798, p. 29.

At a later period he observed "that a sky-blue transparent liquid modified the light of a candle so as to make it similar to daylight; and, of course, restored to pink its proper colour by day, namely, light blue."[1] From this observation he came to a conclusion which he thus states: "It appears therefore almost beyond a doubt that one of the humours of my eye, and of the eyes of my fellows, is a *coloured* medium, probably some modification of blue. I suppose it must be the vitreous humour; otherwise I apprehend it might be discovered by inspection, which has not been done."[2]

Prevost appears to have been the only convert whom Dalton gained to his doctrine, during his lifetime,[3] and an examination of his eyes after death, put an end to any prospect of his theory acquiring new supporters. Mr Ransome, who examined Dalton's eyes, states that "the aqueous humour of one of them was found to be perfectly pellucid and free from colour. *The vitreous humour and its envelope* (the hyaloid membrane) *were also perfectly colourless.* The crystalline lens was slightly amber-coloured, as usual in persons of advanced age. The tunics, retina, choroid and sclerotic, with their subdivisions presented no peculiarity."[4]

Further, on looking through the humours of the other eye (after the posterior portion of the outer coats had been removed), "objects of different colours, both by transmitted and reflected light, were examined without any appreciable difference."[5] Among the colours thus examined, Mr Ransome particularises scarlet and green.

This report of course disposes of Dalton's theory so far as his own case was held to support it; but it is worth a brief consideration with a view to guiding future physiological and pathological researches, whether colour-blindness *ever* depends on alterations in the colour of the optical apparatus of the eye.

Physiologists have not recorded as familiar to them, the occurrence of a blue colour in the transparent, internal portions of the eye. Sir David Brewster, indeed, says, "During the dissection of many hundred eyes, I observed in several cases that the *vitreous humour* was of a decided *greenish-blue* colour."[6] In the human subject, however, this must be rare, for Dr W. Mackenzie of Glasgow (Surgeon Oculist in Scotland to the Queen), whose experience as an eye-surgeon I need not enlarge upon, informs me that he has never witnessed this colour in the vitreous humour of the human eye, which in early and middle life has appeared to him "colourless, and in old age yellowish." As colour-blindness, however, is not regarded, either by its subjects or their medical attendants, as a disease, it is not included within the province of pathology, and in truth, so far as I know, Dalton's case is the only one on record of a post-mortem examination of colour-blind eyes. It must still, therefore,

[1] Op. Cit. p. 41.
[2] Ibid. p. 43.
[3] Taylor's Scientific Memoirs, 1846, p. 182.
[4] Henry's Life of Dalton, p. 202.
[5] Op. et Loc. Cit.
[6] Phil. Mag., August 1844, p. 137.

be regarded as desirable to embrace all opportunities of examining such cases in reference to the point before us.[1]

Wartmann, it is true, affirms that even if the transparent media of the eye were blue, colour-blindness would not be the result: "If," says he, "the passage of the luminous rays through a blue medium sufficed to produce Daltonism, the habitual use of blue glasses for spectacles would have long ago confirmed this hypothesis, against which it forms on the contrary a very strong argument."[2]

But this reasoning is of little value. *Daltonism*, or colour-blindness of the kind which characterised Dalton, might not be induced by a blue vitreous humour, but colour-blindness of some kind certainly would be. The experience of wearers of blue spectacles does not furnish an *experimentum crucis* in reference to Dalton's theory. These are pale in colour, are only worn occasionally, and are generally, in virtue of their unavoidable distance from the orbit, and their form and size, inadequate to exclude entirely white light from the eye. Moreover, most wearers of ordinary spectacles, peep at short intervals over and under them, and then receive the impression of uncoloured light, so that their congenital and acquired perception of hues can only be slightly and transiently disturbed by the coloured media through which they *occasionally* gaze. But if any one will make the experiment of covering the eyes with a sheet of deep red, or green, or blue glass, so pressed to the face as to prevent light reaching them otherwise than through it, and then ask another to show him coloured bodies, he will find himself making as many and as flagrant mistakes as any colour-blind person ever did. I have found even glass-stainers who were accustomed to make allowance for the effect of coloured transparent media in altering the tints of opaque bodies seen through them, err very widely in their conclusions; and others were generally wrong in every colour except that which was identical with the glass through which they were looking. In truth, it needs no proof, that to fill the greater part of the eye with a blue liquid, through which alone light is permitted to reach the retina, cannot fail to induce a peculiar vision of colours, and that this cause of *chromatopseudopsis* (properly so called), is worth the attention of physiologists and pathologists.

At the same time, I entirely agree with Wartmann, in thinking

[1] The infrequency of such opportunities, and the corresponding desirableness of improving them, is strikingly shown by the following statement with which Dr Mackenzie has favoured me:—

"A curious fact about colour-blindness is the extreme rarity with which the subjects of it apply for advice to oculists regarding it.

"During the last thirty years I have treated at the eye infirmary and in private, upwards of 4000 cases of eye disease; and out of this number I do not recollect more than two of colour-blindness. One of these was a calico-printer, distinguished for his taste and success in his own line, and very unwilling to let his defect be known. I suspect this is generally the feeling of colour-blind people."

[2] Taylor's Scient. Mem, 1846, p. 182.

that Dalton's theory "could not explain the diversity of names given to the same colour by different Daltonians."[1] A colour-blindness, indeed, dependent on the humours of the eye being coloured, would be of a much simpler and more uniform kind than that characterising the cases which I have described. As exhibited by an eye otherwise perfect, it would show itself as a "constant error," the extent of which could, by comparison with the vision of normal eyes, be ascertained and allowed for; and as it could not occur in any marked degree, unless the humours were deeply coloured, it would be accompanied (especially if they were red or blue) with a faint perception, in virtue of their imperfect illumination, of the forms and outlines, as well as of the tints of bodies; whereas true colour-blindness does not necessarily, or even generally, involve in doubt the discrimination of aught but their colours.

A colour-blindness of this kind should also be characterised by that colour being seen best (*i.e.*, most normally), which tinged the transparent media of the eye. A blue vitreous humour, manifestly, would not prevent *blue*, nor a red one *red*, from being seen (a difference of shade only excepted) as normal eyes see them; and if true colour-blindness were thus chromatic in its origin, it is *yellow*, not blue, which should be found predominating in the eyes of those who share in Dalton's peculiarity, for yellow is the colour which they see best. But there is no reason to think that the slight tinge of this colour which was found after death in the lens of Dalton's own eyes, was at all more intense than that which appears in the eyes of those who, with a perfect perception of colours, live to so advanced an age as he did. Moreover, Mr Ransome's observations on the unchanged aspect to his eye of red and green, *ex. gr.*, when seen through the transparent media of the deceased philosopher's eyes, render needless any further proof that colour-blindness, such as Dalton's, could not be induced by the change in colour which the crystalline body had undergone. This change, which, as occurring in advanced life in the lens, goes the length of developing in it an amber colour, in addition to a paler yellow tint in the vitreous humour, does not, according to the universal testimony of eye-surgeons, lead to any alteration in the judgments of colours. In truth, the aged are, in one respect, gainers by this coloration of the humours, for there is good reason to believe that Sir D. Brewster is right in his opinion, that "the retina receives a more powerful luminous impression from yellow light, than from the pure white light of which this yellow forms but a part;"[2] and if this conclusion be just, the diminished sensibility of the retina in advanced life is, to some extent, atoned for by the altered colour of the light which falls upon it. There must, unquestionably, be some slight change in the perception of tints, as a drawback to the gain from increased illumination, but this altera-

[1] Op. et Loc. Cit.
[2] Lond. and Ed. Phil. Mag., 1844, p. 139.

tion has, no doubt, occurred too gradually to be sensible to the subject of it.

Sir David Brewster's chromatic theory of colour-blindness is referred to by himself, simply as a conjecture, and is best given in his own words. He is replying to a criticism of Wartmann's, and after some remarks continues :—"During the dissection of many hundred eyes, I observed in several cases . . . . that the *retina* had a marked *French grey* or *pale blue* tint, which decidedly absorbed red light. I knew that in cases of colour-blindness the vitreous humour was not *blue*, or even *greenish-blue*, as Dr Dalton conjectured; but I could not assert that in the same cases the retina might not be blue, and hence I was led to hazard the idea of a blue retina as one which might be admissible as a cause of colour-blindness, but *only on the supposition* that the choroid coat should prove to be the seat of vision."[1]

I am not aware that Sir David has sought, in later publications, to extend this supposition into a full conclusion. He is at one with the majority of philosophers in regarding the retina as the seat of vision; but his conjecture deserves notice as calling attention to the *colour* of the retina as a possible cause of colour-blindness. I do not know by what arguments it could be rendered probable, that the choroid coat performs the function usually ascribed to the expansion of the optic nerve; but excluding altogether the supposition that it can, it appears to me that a coloured retina could not fail to alter the perception of colours, even on the received view that it is itself the seat of vision. To this, and to certain other speculations concerning the extent to which the colours of the *membranes* within the eye may alter its chromatic perceptions, I now turn.

The subject may be conveniently discussed under three heads,

1. Relation of the general colour of the retina to colour-vision.
2. Relation of the *yellow spot* of the retina to colour-vision.
3. Relation of the colour of the choroid to colour-vision.

1. *Relation of the General Colour of the Retina to Colour-Vision.*

It would be putting a question which no one can answer, to inquire, Can the retina transmit to the brain, or determine in the mind, the sensation of its own colour? But it is more within our power to answer the allied question, Would the possessor of *ex. gr.* a blue retina have a different perception of blue, from the possessor of the normal pinkish grey one? I think he would, whatever answer be given to the previous query.

A man of genius has declared that the "eye sees all things but itself," but this fine thought is only partially true, for physiologists have long been aware that by many devices (such as the very simple one of moving the eye tremulously, whilst looking through a very

[1] Lond. and Ed. Phil. Mag., 1844, p. 137.

small hole in a card at the clear sky), the retina may be made visible to itself, or at least a perfect spectral copy of it, becomes an object of consciousness. Such being the case, it does not seem to admit of doubt, that were an individual retina to have a marked colour developed in it, this also would be perceived; and that when the possessor of such a retina made the familiar experiment of looking, till the eye was fatigued, at one colour, the complementary colour which then appeared would be tinged by an added hue from the retina.

But apart altogether from this, a coloured retina, though transparent, would certainly reflect some coloured light, and this light, falling on an opposite portion of the membrane, would produce the same impression, as light of the same quality from any other source would do. It seems to me, therefore, certain that, admitting the retina to be physically the seat of vision, its colour, if at all considerable, would render the perception of colours abnormal.

Now, accordingly, that oculists, by means of their ingenious *specula*, can perceive the condition of the retina during life, it would be important to know whether it exhibits a different colour in the colour-blind, than it does in those whose vision is normal; and similar observations could be made in *post-mortem* examinations.

Since writing the above, through the kindness of Dr W. R. Sanders, Curator of the Museum of the College of Surgeons, Edinburgh, who first made his countrymen acquainted with the eye-speculum of that accomplished physiologist and natural philosopher, Professor Helmholtz of Koenigsberg,[1] I have had an opportunity of observing, how strikingly the innermost recesses of the living eye can be rendered visible by no more complex apparatus than a gas-flame and a slip of glass. It is very startling to see what for ages has been named the *camera obscura* of the eye light up in a moment into a dazzling *camera lucida*, sending through the pupil, brilliant white, brassy, or crimson-coloured rays, according as the movements of the eye-ball make the optic nerve, the "yellow spot," or the blood-vessels of the retina, the more immediate reflectors of the light which issues. No one who witnesses this very beautiful phenomenon will need further proof that the retina reflects in its normal state much coloured light, which, when the pupil is contracted, must, in considerable part, return from the back of the iris to the retina, and impress it as coloured light from without would do. And if this be the case, *à fortiori* the development in any marked degree of a tint such as blue or red on the whole retina must alter the visual perception of colours.[2]

It does not appear that, hitherto, variations in the general colour of the retina have been observed, at least, in the human subject. Dr

[1] Edinburgh Monthly Journal of Medical Science, July 1852, p. 40.

[2] Helmholtz's description of the apparatus referred to in the text is contained in his work entitled "Beschreibung eines Augen-Spiegels zur untersuchung der Netzhaut im lebenden Auge. Berlin, 1851."

W. Mackenzie informs me that he has never seen it in healthy eyes, other then "reddish or pinkish grey," and such appears to be the general opinion of physiologists who compare it in tint to the grey substance of the brain. I do not anticipate that the tint of the retina will be found to vary much in different persons, but it is one of the points deserving attention in the examination of the eyes of the colour blind.

2. *Relation of the* Yellow Spot *of the Retina to Colour-Vision.*

The remarks previously made apply strictly to the *general* colour of the entire retina, but it appears to me singular, that no physiologist has connected the existence of the normal *yellow spot* (the *macula lutea*, or *limbus luteus* of its discoverer, *Sœmmerring*) on the human retina, with the perception of colour; but in truth, so far as I am aware, no physiologist has suggested any use for it. The spot in question is thus described by a recent authority:—

"If we cut across a fresh human eye, so as to look at the hyaloid surface of the retina, or if we carefully remove the sclerotic and choroid coats, so as to expose to view its choroidal aspect, we are struck with the rich yellow colour of one small spot about one-twelfth of an inch in diameter, situated at the very bottom of the eye, in the exact axis of the humours, *i.e.*, at about one-tenth of an inch from the optic nerve. The colour is deepest in the young adult, much fainter in the old. It exists in some monkeys, and according to Dr Knox, in certain reptiles; but in general it is wanting among the lower animals, while it is quite constant in man. The colour shades gradually off, and is deepest when seen from the inside." [1]

The same author, writing in conjunction with Dr Todd, refers further to the yellow spot in these terms: "It has been described by some as a fold, by others as a foramen in the retina, and after several examinations, we should speak of it as a small mound, or projection of the retina towards the vitreous humour, with a minute aperture in the summit. . . . . As for the colouring matter, it is not in grains of pigment, but stains the several tissues, and soon disappears in water. *The use of the yellow spot is unknown.* It is interesting to observe in connection with the perfection of vision over the spot, that the principal branches of the artery and vein of the retina, above and below, curve round it at a distance, going, as it were, out of their course to avoid it, so that only capillary vessels are found in its immediate vicinity." [2]

There are differences of opinion among physiologists (into which I do not enter), as to the exact structure of the retina at the *limbus luteus*, but all are agreed that from its position at the bottom of the eye in the very axis of vision, it must in man receive the most perfect image of an object which the eye, considered as an optical instrument, can produce; and the production of which we instinctively

[1] Lectures on the Eye, by W. Bowman, 1849, p. 89.
[2] Todd and Bowman's Physiological Anatomy, chap. xvii. p. 30.

secure by turning the centre of each pupil towards those bodies which we wish to perceive most accurately. "Perhaps," observe Todd and Bowman, "it is only in, or very near, the axis of vision, that sight can be said to be *perfect*. The existence of the yellow spot of Sœmmerring at that point, continues a riddle which the most attentive examination of its anatomy has not yet solved. And from the absence of this spot in almost all the lower animals, we are led to doubt its importance to perfect vision." [1]

The almost exclusive limitation of the yellow spot to the eye of man, points to some special service which it renders him; and I hazard the following suggestions in reference to it. According to the testimony of all who have described it, it is exceedingly transparent, and as the retina is of sensible and even measurable thickness, the light which falls upon its vertex, and passes through the *limbus luteus*, must lose most of its blue and red rays before it traverses its thickness and fully impresses it. *It is truly thus by yellow, not by white light, that ordinary perfect vision is exercised by man*, and I cannot help connecting this fact with the special sensitiveness of the retina to yellow light.

The yellow rays of the spectrum are confessedly more luminous than the others, and even seem to make a stronger luminous impression on the eye, than the composite white light (of which the yellow is but a part) does. It has further been amply shown in the preceding pages, that yellow is the colour seen best by all human eyes. I suggest, therefore, that the spot of Sœmmerring is a provision for securing to the human retina the conversion of white light into the more exciting yellow light, which makes the maximum impression upon it.

Nor must it be forgotten that the light which traverses the yellow spot will be deprived, not only of its red and blue, but also of its *actinic* or *chemical rays*, which are notoriously stopped by transparent *yellow media*. What influence these rays exert upon the vision, either of form or of colour, we do not know; but they cannot fail to affect it, for the retina, like the other portions of the nervous system, is throughout life continually undergoing chemical changes, which are essential to the performance of its function, and these will be quickened, retarded, or altered in their character by the actinic agencies. Now, the yellow spot which absorbs, and retains within its thickness a much larger proportion of the actinic rays which reach it, than other parts of the transparent retina can, must be the seat of chemical changes, differing in kind or degree from those which they undergo; implying a different amount of molecular disturbance; and, as can scarcely be doubted, occasioning a different sensational impression. It may reasonably be inferred, that this impression enhances the perfection of vision, and that one object of the yellow spot is to secure its production. And if such be

[1] Op. Cit., chap. xvii. p. 55.

the case, we can understand why the retina was made yellow, rather than the humours of the eye; for had they been of this colour, the light which traversed them would have lost its actinic rays (besides parting with its red and blue, and heat-rays), before it reached the retina; and the impression produced by white light containing a large proportion of its actinic, chromatic, and thermic forces, till the moment of its traversing the retina and changing into yellow light within its substance, must be very different from that occasioned by light which has been filtered through yellow media before it falls upon the retina.[1]

But whatever be the value of these suggestions, it does not, I think, admit of doubt, that the colour of objects must seem different to us, than it does to the great majority of animals in whose eyes there is no yellow spot. Their *white* must be *whiter* than ours, their yellow *less* yellow; and all tints must wear for us "a *jaundiced*" look which they do not show to them. It is already ascertained also, that the colour of the *limbus luteus* grows fainter as life advances, and we may well believe that it varies in area, as well as in intensity of tint in different individuals, whose judgments of colours must in a corresponding degree vary. I do not think that such variations can occasion colour-blindness, but they must occasion diversities of judgment among those who, unlike the truly colour-blind, are prompt and unhesitating in their chromatic decisions.

Examples of these diversities occur every day, among those who have spent the greater part of their lives in dealing with colours. Every one must be familiar with the differences which appear among colourists, otherwise equally practised, in their decisions regarding the less-marked tints and shades. Who has not heard painters, and critics of their works, discuss by the hour "flesh-colour," or "sea-green," without any change of opinion among the disputants as to the true quality of these colours? This is not the result, on the part at least of the majority of those differing in opinion, of colour-blindness, for its subjects are not pertinacious in their conclusions regarding colour, and are not given to dispute regarding it.

I have been much struck with the same phenomenon as appearing among dealers in coloured goods, and dyers. The remark has been spontaneously made to me (and on that account impressed me the more) on four different occasions, by the heads of carpet manufactories and dye-works in Edinburgh and Paisley, that they were quite accustomed to find workmen who would "match" unerringly or dye to a pattern, reds, blues, yellows, greens, purples, browns, and most of the other mixed colours, but who failed to satisfy others

[1] The diathermancy of the humours of the eye is very small, so that few of the heat-rays which fall upon the cornea reach the retina: the actinic rays are said also to be stopped by the transparent media of the eye, but the evidence of this is not satisfactory.

with such tints as "drab," "fawn," or "stone-colour," although as well pleased themselves with their adjustments of these as with those of other colours.

Astronomers who seek to give to their estimate of the colours of the heavenly bodies, the same precision as to that of their other characters, supply still more unequivocal proofs of the existence of what they happily term a "chromatic personal equation" in most individuals.

The learned and ingenious Captain (now Admiral) W. H. Smyth, referring to the different colour which appears in the two components of many of the binary stars, observes, in allusion to the extensive researches of Struve on this point:—"Professor Struve's chromatic designations are, *obscurissima*, *obscura*, *pallida*, *livida*, *sub-flava*, *flava*, *sub-caerulea*, *caerulea*, *rubicunda*, and *rubra;* he supposes the ninth magnitude to be the outside boundary in which he recognises colour, but I have been much struck with the beautiful blue tint of the smallest stars visible in my telescope. This, however, may be attributed to some optical peculiarity. The Professor found, what I have also experienced, that Sir William Herschel saw most objects with a redder tinge than they have since proved to bear. This may be owing to the effect of his metallic mirror, or to some peculiarity of vision, or perhaps both.[1]

Here are three unusually skilful observers, with (as there is every reason to believe), in each case, what must be called a normal sense of colour, differing by a *constant* amount regarding certain tints. And as Admiral Smyth observes elsewhere, in commenting on this and similar facts, "a personal [chromatic] equation, of greater or less amount, occurs in every case, and the reason of the faulty colouring of so many artists, is, that they really are not aware of many of the refinements of colour; their eyes not perceiving them, their fingers cannot render them."[2]

One probable cause of such chromatic idiosyncracies in the normal-eyed, and one source of aggravation of those occurring in the colour-blind, is the condition of the yellow spot as to area, thickness, intensity of tint, and the like; for both by the change which it induces on the light which traverses it, and by the light of its own colour which it reflects across the chamber of the eye, it must influence the impression which coloured objects make upon the entire retina.

I would suggest, accordingly, the inspection by means of such an instrument as the retina-speculum of Helmholtz, of the yellow spot in the living eye, in connection with its powers of vision as regards form, outline, and, not least, colour, as well worth the attention of observers. We may reasonably hope to find a close connection subsisting between the extent and tint of the coloured

[1] Cycle of Celestial Objects, vol. i., p. 302.
[2] Aedes Hartwellianæ, p. 311, where the whole passage is worth study.

spot and the visual powers of the eye, and it would be important to know what differences it presents in those whose colour-vision is normal, and those in whom it is the reverse.

There are difficulties, doubtless, in the way of such observations, which can be made to purpose only by experienced oculists. The appearance of the yellow spot in a perfect eye, as seen by Helmholtz's speculum is thus described by Dr Sanders :—"The retina surrounding the white optic nerve is of a bright red colour, which becomes deeper towards the periphery, and is caused probably by the capillary blood-vessels, too small and too faintly illuminated to be distinguished from the grey substance of the retina. . . . . The yellow spot of Sœmmerring or spot of direct vision, is of a dimmer yellowish-grey colour, without trace of capillary vessels; its observation is rendered difficult by reflection from the cornea; and the luminous image is much less bright than on the adjoining parts of the retina."[1]

These remarks apply, of course, solely to the vision of man; but although the yellow spot is not found in the retina of the majority of the lower animals, certain remarkable coloured objects occur in the "rods and bulbs" of that membrane in these creatures, which, like the yellow spot of the human eye, may affect the vision of colour. The objects in question show themselves in the outer or choroidal ends of the rods and bulbs as "globules resembling oil, either colourless or possessing most brilliant tints of yellow or crimson. In the Chelonian reptiles and in birds these are the most beautiful."[2]

A portion of the retina of the tortoise, Mr Bowman tells us, shows on its outer aspect, when seen through the microscope, "a most elegant array of pale, of yellow, and of crimson globules, scattered with regularity over the surface, the first being the smallest, and the last the largest, ...

"In birds we have even a more beautiful pattern of colours. In the sturgeon, among fishes, I have found the globules large but colourless. In the mammalia they are either very small or wanting."[3]

I am informed that the skilful histologist, Hannover, has made these singular bodies objects of special observation, and has figured them in his "Recherches Microscopiques sur le Système Nerveux, 1844." The subject is one lying beyond the compass of my familiar knowledge; but these remarks may perhaps induce competent inquirers to study the globules in the retina of many of the lower animals in relation to their possible influence on the vision of colour.

[1] Edinburgh Monthly Medical Journal, July 1852, p. 44.
[2] Bowman on Vision, p. 88. [3] Op. et Loc. Cit.

3. *Relation of the Colour of the Choroid to Colour-Vision.*

If the proposition be well founded, that the colour of the internal membranes of the eye must affect its perception of colours, then the choroid, which is the most fully coloured of the tunics, and the one most liable to vary in extent and depth of coloration, must have a very important influence on colour-vision.

In the normal human eye, the matter colouring the choroid and posterior surface of the iris, is rather a *pigmentum fuscum*, than *nigrum*, and is described as possessing a reddish-brown, a sepia, or tobacco-brown tint. The amount of pigment and its particular shade, vary in different individuals, according, especially, to age and race. In the young it is much darker than in the aged, and it is more abundant and deeper in tint in the dark than the fair races of mankind.

Vision is held to be in all respects most perfect, when *ceteris paribus*, the *pigmentum nigrum* is darkest, and by absorbing the rays which have traversed the transparent retina, prevents the interfering influence of cross lights within the chamber of the eye; but I shall presently have occasion to show that this opinion calls for qualification.

In the eyes of the aged, where the pigmentum nigrum becomes very pale, and in those of the albino, where it is in great part or altogether awanting, there is manifest reflection of light from the choroid;[1] but, in truth, by Helmholtz's arrangements, the choroid of every healthy human eye can be shown to reflect much light; and as this light in moving towards the pupil, traverses the retina, including the yellow spot, as well as the blood-vessels, it must (even if originally colourless) become coloured in its passage. The great distinction, accordingly, which has been drawn between the mirrorless *camera obscura* of the human eye, and the brilliant *tapetum lucidum* which, like a concave metallic mirror, lies behind a large part of the retina in the eyes of many of the lower animals, is, in reality, much less marked than it has been held to be. Without, indeed, the aid of any optical apparatus, the human eye can be seen to glare and flash as that of a cat does; and from a very early period the observation has been made, that the eyes of certain persons "shine in the dark." Dr Esser has collected several striking examples of this as occurring in albinos, but it is not confined to them.[2] The late Professor Jameson of Edinburgh states, that he had remarked a luminous property like that of the cat's eye, "in the eyes of several individuals, principally females;"[3] and Mr Cumming, before Helmholtz published, had shown, "that in the eyes of all persons, where the pupil is tolerably large, a very decided reflection from the bottom of the eye may be observed by placing the individual under

[1] Mackenzie's Physiology of Vision, p. 218.

[2] On the Luminousness observed in the Eyes of Human Beings, etc. Edin. Phil. Journal, 1827, p. 164.

[3] Op. Cit., p. 301.

trial at a distance of ten feet from a single gaslight, and directing him to look a little on one side, when a strong glare becomes visible to any one standing almost directly between him and the light. In some persons this glare is exceedingly brilliant, like that from burnished brass; in others it is fainter."[1] Similar observations were made at a later period by Brücke;[2] and before either of these experimenters had recorded his results, Dr Mackenzie had stated that: "In one instance, Sir David Brewster saw a reflection of a bright red colour, with a purplish tinge, from the bottom of the eye of a boy about ten years of age. In a girl at the Glasgow Eye Infirmary, I noticed also a purple reflection."[3]

The light, which in so many ways can be shown to be reflected from the interior of the eye, is of course thrown back in part only from the choroid. But that this membrane contributes largely to the reflection, may be shown by the colour of the light which issues from the eyes of those animals which are provided with a *tapetum lucidum*, and from the colour of the pupil of the albino. In both cases the tint *corresponds* to that of the choroid. It could not be expected to be strictly identical, for the choroid being behind all the membranes but the sclerotic, the light it reflects must traverse them and have its colour altered in its passage, so that besides the influence of the *yellow spot* in colouring this light, we may always expect an addition of red from the blood-vessels. After making due allowance for this, however, we shall find the proposition hold good, that the pale choroid of the aged man, the red choroid of the albino, and the silvery green tapetal choroid of the sheep, reflect respectively a yellow, a red, and a green light.

It comes, then, to be a matter of interest to inquire, what influence such coloured light will have on the vision of colours: and as the eyes of those animals which have shining *tapeta*, exhibit coloured reflection more strikingly than the human eye normally does, I shall refer first to them, as well as to the albino's eye, where there is so great an abnormal reflection of coloured light, before considering the reflecting power of the choroid in ordinary eyes.

The *tapetum lucidum* presents such an appearance in bright light, as we might expect in a piece of *metallic velvet, i.e.*, velvet woven from the finest and most polished capillary threads of gold or silver wire. It is thus described by Todd and Bowman:—"In many quadrupeds and fishes the inner surface of the choroid, in its posterior part, has a brilliant lustre, owing to the presence of a thick layer of wavy fibrous tissue, peculiarly arranged, outside the choroidal epithelium (here colourless)."[4] The appearance of this *tapetum lucidum* varies in different animals, as will be seen from the

[1] Medico-Chir. Trans. Lond., vol. xxix. p. 283. Quoted in Todd and Bowman's Physiological Anatomy, chap. xvii. p. 51.
[2] Müller's Archiv., 1847, p. 225.
[3] Physiology of Vision, p. 218, 1841.
[4] Physiol. Anatomy of Man, chap. xvii. p. 23.

following description by Cuvier, which contains the fullest account I have been able to find of these variations. It leaves unnoticed, however, a large number of creatures.

After referring to the Ruyschian membrane (the inner surface or layer of the choroid) as more or less covered with a dark varnish (*pigmentum nigrum*), he continues :—"The bottom of the Ruyschian membrane is covered only with a very thin layer of this varnish, through which its colour, which varies singularly in different species, is perceived. In man and monkeys it is brown or blackish ; in hares, rabbits, and hogs, of a chocolate-brown ; but the carnivora, the ruminantia, the pachydermata, the solipeda, and the cetacea, have bright and shining colours in this part. The ox has it of a beautiful golden green changing into celestial blue ; the horse, the goat, the buffalo, the deer (*cerf*), of a silvery blue changing into violet ; the sheep of a pale golden green, sometimes bluish ; the lion, the cat, the bear, and the dolphin, have it of a pale golden yellow ; the dog, the wolf, and the badger, of a pure white bordered with blue. This coloured part of the *Ruyschian membrane* is named 'le *tapis*,' [tapetum]. It does not occupy the whole of the bottom of the eye, but only that part which is not penetrated by the optic nerve."[1] In another part of this *leçon*, Cuvier refers to the *ray* (which is the only fish mentioned by him) as having the bottom of the eye of a "beautiful silvery colour." It may be added that the eyes of more than one species of shark present the same appearance, and judging from specimens preserved in spirits, where the *tapetum* looks through the semitransparent retina like tinfoil, and when the retina is removed, like dulled silver, I infer that in the living eye, the reflecting surface resembles this metal when purest and most polished, in colourlessness and brilliancy.

How far the enumeration given above exhausts the diversities of colour observed in the *tapeta* of different creatures, must be regarded as uncertain, since whole divisions of the animal kingdom are unrepresented in the list. The recorded diversities are after all, small. In fishes the tapetum may be compared to a concave mirror of bright silver. In other animals it is such a mirror coated as it were with a transparent blue, green or yellow varnish ; but except a tinge of violet, it is never red. Assuming the tapetum to act as a reflecting speculum in the living eye (as I think it will presently appear it certainly does), then a reason can be seen for its colourlessness in fishes, inasmuch as the medium in which they live is itself in mass coloured, and absorbs a very large amount of the solar and sidereal light which falls upon it, so that at considerable depths there is comparative darkness, and the faint twilight which prevails will certainly be reflected with less loss by a colourless tapetum than it would be by a coloured one. Moreover, the pale phosphorescent light of the sea, which must be regarded as to a considerable extent

[1] Leçons d'Anatomie Comparée, (xiie leçon) ; 2de Edition, t. iij., p. 413, 1845.

a substitute in its darker regions, for the celestial light of which they receive so little, has so feeble a luminous intensity, that its illuminating power would be much lessened by reflection from a coloured surface, and a silvery white tapetum can turn to best account its faint rays.[1]

That the tapetum of no animal's eye is in its normal condition red, appears sufficiently accounted for by two considerations:—1. *Red* light of feeble intensity impresses the retina less than faint light of any other colour (ante p. 53), so that if the tapetum acts as a reflector, and is most serviceable when the quantity and intensity of the light entering the eye are smallest, the worst tint it could possess would be a red one. 2. The transparent blood-vessels ramifying on the retina, and in other parts of the eye in front of the tapetum, colour the light which it reflects through them, so that there is in all animals, an unavoidable reddening of the light issuing from their eyes, and a corresponding diminution of its illuminating power. With a red tapetum this diminution would be still greater.

So far, then, as our knowledge goes, the metalline tapetum is frequently white, sometimes yellow, but in the majority of land animals either blue or green; and I am now to consider the question what influence will the emission of, *ex. gr.*, blue or green light from a living animal's eyes have upon its perception of colour? It will conduce to perspicuity to take a single unquestionable example of such emission of coloured light from the living eye, and no more striking or familiar instance of this could be wished than that furnished by the common cat, whose eyes proverbially "shine *green* in the dark." The tapetum of this animal is yellow, but the light reflected from it acquires a green colour before leaving the eye. This is not a vulgar fancy. Dr Esser, who made a great many experiments on the luminousness of cats' eyes both before and after death, mentions that when a few rays of sunlight were allowed to fall obliquely on the face of a living cat whose eyes were in a straight line with his own, he "observed a most beautiful green light;" and in twilight "a yellowish green." The eyes of a cat just beheaded shone far more vividly when its face was turned to the sun, than those of the living animal, in consequence of the permanent dilatation of the

[1] In addition to its tapetum a fish has another *moveable* ocular mirror in its golden or silvery iris. The external appearance of a fish's eye, with the incontractile brilliant iris surrounding the large crystalline, exactly recalls the appendage attached to microscopes for condensing light on opaque objects, called from its inventor a Lieberkuhn, and consisting of a circular metallic speculum, with an aperture in the centre occupied by a lens. In truth, however, the majority of fishes are altogether living mirrors; the metallic brilliancy of their skins or scales making them powerful reflectors. Those who have noticed to what an extent, in a dark night, the phosphorescence of the sea, although fainter than early twilight, will render visible fishes in the water, at a considerable distance from the observer, in virtue of their high reflecting power, must have been struck by the many beautiful provisions which have been made for economising to the utmost the small amount of light which reaches, or is generated within, the depths of the sea.

iris after death allowing a larger pencil of light to enter and leave the eye. The light then emitted "resembled," says Esser, "the most beautiful green fire."[1]

Seeing, then, that a cat's eyes certainly emit green light in particular circumstances, how far will its judgments of colours seen by that light be affected by this? Some preliminary difficulties must be disposed of before this question, involving in considerable part that of the relation of a coloured choroid to the vision of colours, can be considered.

In the first place, there is still some reluctance to come to a unanimous conclusion regarding the source of the light which renders the eyes of many animals luminous "in the dark." The popular belief, vaguely acquiesced in by some naturalists is, that the eyes of the cat and of other creatures shine by a light of their own, which is the more conspicuous, the more absolute the darkness which it encounters. But the experiments of Esser,[2] and of Benedict Prevost,[3] incontestably prove that in utter darkness the eyes of all the higher animals very soon cease to be luminous,[4] and that within certain limits they may be made to shine at the will of the experimenter by allowing light to fall upon them.

It is possible that the vitreous and other humours, in the eyes of animals, are phosphorescent, in the way transparent bodies like the

[1] Edinburgh Philosophical Journal, 1827, pp. 164, 167. My friend Mr William Swan, at my request, examined with Helmholtz's speculum the eyes of his cat which is an unusually large and powerful male, with the following result :—"The colour of the tapetum, or that of the light reflected from it is what I should call an apple green, sometimes passing into nearly pure yellow. The former colour I have often seen when looking at his eyes without the intervention of the speculum."

I have found no difficulty in making similar observations on the eyes of a dog, who, by a little coaxing and bribing, was persuaded to look in such a direction that the light of a gas flame could be reflected into his eyes. The light returned from them was generally a yellow like that of illuminated brass, but in certain positions of the eye-balls, it became a full crimson, when, as I presume, the larger blood-vessels acted either as reflectors or transmitters of the light.

I mention these particulars because they show that a series of very interesting observations could be made by means of specula, not only on the domesticated animals, but also on the less controllable inhabitants of our zoological gardens, as to the amount and colour of the light which their eyes (whether provided or not with tapeta) emit. Any animal with its head at rest and its face fronting the observer, but especially those with tapeta, could be thus examined with the assistance of a mirror by daylight, and a moveable flame by night; and it is only by such observations that the quality of the light which the eyes of all creatures give out can be ascertained. The colour of the tapetum, does not, as some have supposed, alone determine the colour of the light which leaves the cornea; and where there is no tapetum it is still more difficult to predict what the colour of the issuing light should be.

[2] Op. et loc. cit.

[3] Ibid, p. 297.

[4] I do not know how the case stands with insects, such as moths whose eyes shine in the dark, but whether from mere reflection or a true phosphorescence does not appear to have been certainly ascertained.

diamond are, which, when transferred to total darkness after exposure to light, shine for a time. But if the eye is thus endowed, its power to phosphoresce is very slight, and not less transient; and it is certainly as a reflector of light incident on it from without, that the tapetum mainly confers luminosity on the eye of which it is a part. The point is important to my discussion, inasmuch as it shows that the coloured light issuing from the eyes of animals possessed of tapeta, has in great part been reflected from the very bottom of the eye, and has thus completely traversed its transparent media, before its emission; so that every portion of the retina is liable to be impressed by it.

The action of the tapetum is thus sufficiently manifest; but many able physiologists have found great difficulty in assigning a function (or at least a useful one) to it, and there seems no agreement regarding this point. As these difficulties stand in the way of conclusions I wish presently to urge, they must first be disposed of.

Benedict Prevost, after showing that the shining of a cat's eyes is not phosphoric, continues:—"It has also been pretended that it serves as a light to the animals which possess it, and that it assists them in seeing, and guiding themselves in the dark. But the place which the reflectors occupy is reasonably a matter of astonishment; for it is not the light which proceeds from the eye to an object that enables the eye to perceive that object, but the light which arrives in the eye from it."[1] Dr Mackenzie quotes, with approval, this observation, adding the more important comment:—"The purpose served by the reflection of light by the tapetum is not understood. Reasoning *à priori*, we should say it would render the eyes weak and impatient of light."[2] Todd and Bowman observe,—"This *tapetum lucidum* must act as a concave reflector, causing the rays of light to traverse the retina a second time, and thus, probably, increasing the visual power, particularly when the quantity of light admitted into the eye is small."[3] This opinion, Dr Mackenzie thinks "not likely to be just," founding his objection on the absence of a tapetum from the eyes of nocturnal birds, which can see very well in what seems to human eyes absolute darkness.[4]

Prevost's observations seem scarcely called for. If any one certainly has imagined, that the mere lighting up of an animal's eyes would confer upon them the power of vision in darkness, although the light issuing from those eyes was not returned to them from the objects which it rendered visible, the fallacy of his notion deserved to be exposed. But those who held such a view can have had no clear idea of the relation of vision to light from external sources, and it is unnecessary to discuss minutely their opinions. Prevost, however, in dismissing these, appears to think that he has disposed of the question—Does the light issuing from an animal's eyes assist in render-

[1] Edin. Phil. Journal, 1827, p. 302.
[2] Physiology of Vision, p. 220.
[3] Physiology of Man, etc., chap. xvii., p. 23.
[4] Physiology of Vision, p. 221.

ing objects visible to it? and, finding no manner of use for this light, gravely proposes the singular doctrine, that the use of the tapetum is continually to empty the eye, especially during the day, of the superabundant light, which, if not sent off, would lessen its delicacy of visual perception! It is plain, however, that the light thus expelled from the eye, whenever it fell upon a reflecting surface placed in the axis of vision, would in great part be thrown back into the eye, and render visible the object which reflected it. Instead, therefore, of its being a pretence, as Prevost would have us believe, that such an animal as a cat is helped to see by the light issuing from its eyes, it does not admit of doubt that, whether it wills it or not, it cannot help seeing by such light, in so far as it is returned to these organs by the objects on which it falls.

I am at a loss to understand how this function of the tapetum should recently have been so much disregarded. It seems to have fallen out of notice among our physiologists and natural philosophers, although not sharers of Prevost's views; yet I can conceive no reason for this but the supposed feeble intensity of the light which is emitted from the eyes of animals. It is feeble assuredly, compared with sunlight, or even candlelight, but it is bright compared with darkness, and seems the brighter the deeper the darkness. The light of a cat's eyes is not inferior to that of a glow-worm in intensity: yet the light of the latter is seen from a considerable distance, and close at hand, will enable one, whose eyes have been rendered sensitive by darkness, to distinguish minute objects.

What light of such intensity will do for our eyes, it will do for those of a cat, and none the less because it is returned to eyes from which it was given out. It is true, that if the primary source of the light reflected from the tapetum, and thereafter returned to the retina, were some luminary of great brightness such as the sun, or incandescent lime, or charcoal, the low intensity of the returned light would prevent it from impressing the retina; but in intense light, the tapetum is not needed, and, as will presently appear, does not come into play; and, in faint light, where the difference between the luminosity of the primary rays falling on the tapetum and reflected from it, and that of those returning to the eye, is slight, the retina will retain sensitiveness to both. An eye dazzled by sunlight does not perceive candlelight; but candlelight does not paralyse the retina to the faint phosphorescence of a fish which has begun to decay; and a much nearer approach in the relative luminous intensity of two lights may occur without depriving the eye of the power of discerning both. Of this, one proof specially pertinent to the topic under discussion will suffice.

In subjecting one's eye to the scrutiny of Helmholtz's speculum held in the hand of another, the light of a bright gas flame is thrown into the eye, and reflected from the retina and the choroid behind it (as it would be from a tapetum), through the pupil; but though there is the sense of dazzling from the flame, this does not prevent

less brilliant objects from being seen distinctly. These are perceived chiefly by the feebler rays of the flame falling upon them; and I refer to the fact here, simply to illustrate the simultaneous visibility of lights of unequal luminosity; but I notice, in passing, that the light issuing from one's eye, in such an experiment, is brighter than some of the rays of the gas flame, and if reflected from external objects into the eye, would certainly render them visible.

The older physiologists seem fully to have realised this truth, and to have gone beyond its recognition to speculations on the final cause of the existence of a tapetum in the eyes of certain animals. Monro, and as Cuvier states, "d'autres avant lui,—believed that the tapetum of the ox is green, in order to represent more vividly to it the colour of its natural food."[1] And it was probably a similar opinion that led John Hunter to state that, "in the cow, in sheep, deer, horses, and I believe, *in all animals feeding on grass*, there are in the same eye, certain portions of it [the tapetum] white, and others of *a fine green colour*."[2] Monro, at least, and those at one with him, certainly held, that the green light issuing from an ox's eye was reflected back to it from the grass on which it fed, and made it more conspicuous to the animal. This is a particular example of the general conclusion which I wish to urge—that from the eyes of most animals possessed of tapeta, there issues (especially in twilight or partial darkness) coloured light, by which, in part at least, they see objects before them, and necessarily of a different tint from that which such objects present to the eyes of animals without tapeta. No creatures certainly are more free from colour-blindness, or more keenly sensitive to the difference between red and green, than bulls, rams, and turkeys, which are equally roused to madness by the spectacle of the former colour, and equally composedly regard the latter. Yet the same red rag, or green blade of grass, must present a different tint to each; for the ram's tapetum is much greener than the bull's, and the turkey has no tapetum at all. These are examples of a *chromatic equation* in animals, depending on the colour of the choroid, which will prepare us for similar though less decided differences, due to the same cause, in the human eye; but to this I shall return. Before, however, passing to another subject, there is a probable (I would say, indeed, a certain) use of the tapetum in some animals, which, as it appears to have entirely escaped the attention of naturalists, I briefly notice, although it has no direct connection with the vision of colour. Cuvier observes, in reference to Monro's opinion, that its green tapetum assists the ox in finding its green food, that "this explanation does not apply to other species," as assuredly it does not. A cat preys on nothing green, and can receive no special help in finding its food from the light of that colour which issues from its eyes, although it will,

[1] Leçons d'Anatomie Comparée (leçon xij.); 2de edition, t. iij., p. 419.
[2] Catalogue of Museum of R. Coll. of Surgeons in London, vol. iii. p. 162.

simply as light, assist it in surprising its victims. But if such light guides the cat to the mouse, *it warns the mouse of the cat.* There is mercy to the victim as well as to his pursuer, in the endowment of the latter with a brilliant reflecting choroid. The owl, which has no mirrors in his eyes, and owes his acute sight to his large pupil and highly sensitive retina, can steal unperceived in twilight, on his prey; but the flashing green eyes of the lion, the leopard, and the tiger, must often have given timely though unintended warning of their approach to their anticipated victims; and the shark probably cheats himself occasionally of a meal, through the unconscious announcement of his approach, given by the appalling glare of his immense eyes. But this is a digression.

Having then considered the relation of the tapetum to the reflection of light through the pupil on external objects, we are now to look at its relation to the reflection of light from side to side, within the chamber of the eye, with a view to inquire how far vision will be affected by such cross reflections, especially as occurring in the human eye.

The observation of Dr W. Mackenzie (already quoted), that *à priori* reasoning leads us to infer, that the addition of a tapetum to the eye would render it "weak and impatient of light," has great force in it, and has probably been acquiesced in hitherto. A good deal of irregular reflection must occur from a surface so unequal as that of the tapetum is, and the lateral and anterior portions of the retina will receive those scattered rays. It certainly appears, at first sight, as if the resulting multiplication of cross lights could not fail to irritate the retina and confuse the distinctness of vision.

This conclusion, however, I believe, has mainly been drawn from the acknowledged condition of vision in human albinos, where all the evils supposed inseparable from the presence of a tapetum certainly show themselves. But the eye of an albino (animal or human) is, in two important respects, unfavourably circumstanced, compared with that of a cat or other shining-eyed animal. In the first place, the albino's eye has no *pigmentum nigrum* on the lateral and anterior portions of the choroid, any more than on its posterior portion; whereas the tapetum occupies only the latter region, and the rest of the choroid is thickly covered with pigment, and increasingly so anteriorly. In the second place, the iris of the albino is free from pigment behind, and nearly so in front, so that it is transparent, and when contracted to the utmost, offers as large an area for the entrance of light as when it is fully dilated; whereas, in a cat's eye, *ex. gr.*, the iris is virtually opaque, and, when contracted, allows only a very small amount of light to enter.

It is further to be noticed that, except in fishes, and to some extent in the marine mammalia, the area covered by the *tapetum lucidum* corresponds to but a small portion of the bottom of the eye, whereas the arrangement in the albino is equivalent to a conversion of the entire choroid, including the back of the iris, into a reflecting

tapetum. Thus John Hunter states, that the tapetum "is *always* placed at the bottom of the eye, in the shape of a half-moon, with the circular arch upwards, the straight line or diameter passing almost horizontally across the lower edge of the optic nerve. . . . . This shape is peculiar to the cat, lion, dog, and most of the carnivorous tribe; in the herbivorous, the upper edge being irregular." [1]

Moreover, limited as the tapetum is, only a small portion of its surface is brought into action as a reflector, unless when exposed to faint light. This is particularly the case in feline animals, where the elongated pupil is at right angles to the tapetum, and narrows in sunlight to a small chink, allowing only a thread of light to enter; but it is sufficiently striking also, in the eyes of herbivorous animals, where the pupil stretches as a horizontal slit, parallel to the tapetum, but not opposite to it when the iris is contracted. In the albino's eye, on the other hand, only the closure of the eyelids defends the reflecting surface of the choroid from the access of light. The fullest contraction of the iris is but equivalent to the drawing down of a red window-blind: it alters the quality of the light entering the eye, but not the extent of surface on which it falls.

We must thus set aside altogether the albino's eye, as it presents conditions greatly differing from those of the luminous eye possessed of a tapetum: it is with the *normal* human eye that the animal's shining eye should be compared; and it is this analogy which gives special interest to the discussion.

If, then, we look at the circumstances under which the choroidal mirror, or tapetum lucidum comes into play, it appears that it acts only when the light falling upon it is feeble, and the iris is dilated. It is in permanent action, accordingly, only in fishes, in which the iris is immobile, and the eye is always exposed to a subdued light. In land animals, such as the cat, it is, as it were, thrown out of action except in twilight; and the wide-spread belief, even among the educated, that the cat's eyes shine in utter darkness, is the best proof that the feebler the light, the more fully does the tapetum act.

In the *first* place, then, the light falling upon the tapetal surface of the choroid is of low intensity, and therefore easily absorbed by dark surfaces, when reflected upon them. *Secondly*, As the greater number of the rays of light falling on the tapetum will simply retrace their course when reflected from it, they will pass out of the dilated pupil as they passed in, without impinging on the membranes within the eye. *Thirdly*, Those irregularly reflected rays which do not follow this course, will nevertheless in greater part have a direction forwards, so that they will fall upon the back of the iris, or the more anterior lateral portions of the choroid—the ciliary processes, and the ciliary body—and be absorbed by the pigment,

[1] Catalogue of Museum of R. Coll. of Surgeons in London, vol. iii., p. 165.

which is thickest and darkest there. *Fourthly*, Of those rays which are reflected from one point of the shining tapetum to another, only such as fall upon the seat of perfect vision (which occupies a very limited area) can materially interfere with the distinctness of visual perception, and they must be very few.

The arrangement, in short, closely resembles that of a *camera obscura* arranged to take a daguerreotype on a silvered plate, with this exception, that the highly reflecting metallic surface corresponding to the tapetum is flat, not curved, so that reflection from one point of the surface to another, which is most to be dreaded, cannot occur. This difference allowed for, it is still manifest that, if reflection from the silvery surface does not prevent the production of a perfect image on it, the similar reflection from the tapetum should not prevent the production of a perfect image on the retina, which lies like a thin film in front of it.

The presence, then, of a mirror in the back of an animal's eye, appears to be in no respect incompatible with distinct vision; on the other hand, I think there can be no doubt that it greatly enhances it; and I urge this belief because, after the results obtained by Cumming, Brücke, Helmholtz, and others, it does not admit of question that between the *mirrored* animal's eye, and the *mirrorless* human one, there is only a difference of degree. A cat's eye does not more certainly reflect light, than the eyes of every one of us do; and if his sight is disturbed by such reflection, ours must be also. Yet what we call in our own case "perfect vision," is vision thus disturbed, if disturbed it be, and the important question suggests itself, "Does not choroidal reflection increase instead of diminishing the perfection of sight?" According to the current theory of vision it should not improve it. This teaches that the light which has traversed and impressed the retina is thereafter absorbed by the pigment of the choroid, lying behind it, and the more rapid and complete this absorption is, the more perfect, *ex hypothesi*, the picture on the retina. In a word, the whole eye being maintained a *camera obscura*, it is desirable that its posterior wall, or surface, should be *pars obscurissima*. I find no fault with this as a hypothesis; it is probably realised in those sharp-sighted nocturnal animals, such as the lemurs, which have no tapetum, a uniformly tinted choroid, and a very sensitive retina, but it does not apply to the human eye, or to that of a large number of animals. "In those animals," says John Hunter, "where the *pigmentum nigrum* is black, it is pretty uniformly so through the whole; but in those where it is lighter it is not so uniform. The *lightest part is always at the bottom of the eye*, becoming darker gradually forwards, and in such it is often quite black, viz., from the termination of the retina to the pupil; or if not black, it is there much darker than any where else. This is generally the case in the eyes of the human subject."[1]

[1] Catal. Mus. R.C.S., London, vol. iii., p. 133.

Later physiologists do not appear to have looked so particularly into this matter as the great surgeon and comparative anatomist did, but all are agreed as to the increased thickness and darkness of the pigment on the posterior surface of the iris (*uvea*), and the internal surface of the ciliary body, as well as between the folds of the ciliary processes. One great object of the uvea unquestionably is to render the iris opaque, and prevent it from *transmitting* light, but it also deprives it of the power of *reflecting* light, and the internal surfaces of the ciliary body and processes must have an equally low reflecting power. The wisdom of this arrangement is apparent. Seeing that, whether for a beneficial end or not, light is reflected from the bottom of the eye towards the pupil, had the uvea possessed a high reflecting power, it would have returned the light which fell upon it to the bottom of the eye, and thereby have infallibly disturbed vision. The seat of perfect vision is opposite the pupil, so that if it rapidly contracted, the increased surface of the iris would not merely intercept many of the rays which passed through the dilated pupil, but would, if the posterior surface of the iris acted as a reflector, send them back upon the spot of clearest vision, and confuse the image there. The occurrence of this in the eye of the albino is doubtless one of the causes of his imperfect sight.

There is thus, at least, provision made against vision losing in distinctness from deep-seated reflection within the eye, but I venture to suggest that it *gains* in distinctness from it. Let us look first at an eye with a tapetum, where the reflection is greatest. The first effect of this tissue (which I shall further assume to be colourless), acting as a mirror, will be to return the rays of light which fall upon it, *through the retina*. I have already quoted Todd and Bowman's opinion, that this "will probably increase the visual power," and Dr Mackenzie's objection to this conclusion, because quick-sighted night birds have no tapetum. The majority of physiologists take no notice of the matter, and Todd and Bowman's statement is certainly vague. Can it be doubted, however, that what is equivalent to two rays of light falling upon the retina will produce two impressions? We send a capillary sunbeam through the retina in one direction, and instantly return it through that membrane, a little diminished in intensity, in the opposite direction: if it determined a sensation in its first passage, what is there to prevent its doing so in its second? If, for simplicity's sake, we suppose exactly the same points of the retina to be traversed by the incident and the reflected ray, then (unless the luminous intensity of the incident ray was so great as by its passage to exhaust the sensibility of the retina) the reflected ray will repeat somewhat less powerfully the impression made by the incident one. The difference will be as great as there is between a sound and its echo, but not greater.

On this view of matters, the tapetum, especially in twilight, will serve the important purpose of making every perceived ray of light *tell twice* upon the retina, so that the sensation it produces will

either be increased in distinctness, or in duration; and probably in both.

The human eye has no tapetum, and the light reflected from its interior, comes unquestionably in part from the surface of the retina; but the pale surface of the choroid behind the retina also acts as a mirror, and must serve the same purpose as the tapetum in the eyes of the lower animals. The effect of this choroidal reflection on our vision, must be the same as that of tapetal reflection on the visual perception of animals. All optical images will be twice depicted on the retina, and every luminous sensation will make a deeper and more lasting impression upon us, than it otherwise would have done. The pale colour of the choroid at the bottom of the eye, is thus as beautiful a provision for effective vision, as its dark colour in front.[1]

If those conclusions are well-founded, their application to colour-vision is direct. The tapetum in a multitude of animals is coloured, and from this it follows that the impression made upon the retina by the reflected ray, must differ from that produced by the incident one. Thus, the incident ray in all cases being white; in the felidæ the reflected ray will be *yellow;* in the herbivora, it will be *blue* or *green;* and with both we may contrast the albino, where the white incident light will in great part be reflected as *red* light. Colours cannot appear the same to eyes so endowed. The feline, the herbivorous, and the albino eye, must contribute respectively a yellow, a blue or green, and a red tint, to every object they perceive, and must judge differently of the same colour.

There must be similar, though smaller differences, in the normal human eye, for the choroid varies much in tint in the different races and in different individuals. In the Museum of the London College of Surgeons, there is a considerable collection of preparations from the eyes of fair and dark persons of the same and of dissimilar races, specially intended to illustrate this, and also that the colour of the choroid corresponds to that of the hair. John Hunter thus comments on the subject:—"There are few of the human species that we can say are perfectly white. They rather pass from the black into the brown, red, and even light yellow; and we find the *pigmentum*, ... varying through all the different corresponding shades. In the African negro, the blackness of whose hair and skin are great distinguishing charac-

[1] The objection to such views, drawn by Dr Mackenzie from the absence of a tapetum in nocturnal birds, is valid against those who hold that only by an internal mirror can vision by dim light be secured. I do not advocate this opinion, for, plainly, great dilatability of the pupil, and exalted sensitiveness of the retina, will secure this power for a mirrorless eye; and physiology abounds with examples of similar results secured by dissimilar causes. I would notice, however, that there is an anatomical objection to the occurrence of a tapetum in the eyes of birds, in the occupation of its site by the singular organ called the *marsupium*, or *pecten*, which is supposed to take part in the adaptation of the eye to vision at different distances.

teristics, the pigmentum is also very black. In the mulatto, who has not the skin so dark as the African, but the hair nearly as black, this pigmentum is of a shade not quite so deep, yet still it does not approach so near to the middle tint as the skin, rather following the colour of the hair. In people of a swarthy complexion, as Indians, Turks, Tartars, Moors, etc., we find the hair always of a jet black, and this substance of a much darker brown than in those that are fair. In people remarkably fair, ... we find this pigmentum following the colour of the skin and hair; being in some of a light brown, and in others [albinos] almost white, according to the colour of the hair in such people."[1]

There are thus (excluding the albino) variations of colour in the human choroid from pale yellow to the darkest brown, which must, more or less, be communicated to the light reflected through the retina, from the membrane behind it, and affect the perception of colour. Apart from individual differences in the judgment of tints occasioned by this, there must be constant national ones. The dark and the fair races will present a different "chromatic equation;" the advantage, so far as normal perception of colour is concerned, being probably with the dark-eyed, in whom the deeply-tinted choroid will reflect less coloured light to add its impression to that of light from without, than will be the case with the paler choroid of the fair races.

On reviewing what has been stated in the three preceding sections (*ante* p. 81), on the general colour of the retina; on the special colour of its yellow spot; and on the many variations in colour which appear in the choroid, it is manifest that though the light furnished by the sun, or by artificial luminaries, may reach a number of living eyes unaltered in quality, it will be so altered in colour within them, by the influence of the membranes referred to, that very different chromatic perceptions will be determined by the same primary light. Within the eyeball, unquestionably, there will be, to some extent, a neutralisation of coloured rays by their complements, ending in their conversion into white light, or in their entire extinction. Of this, one striking example is afforded by the eyes of herbivorous animals, where the light reflected from a green tapetum, afterwards passes through transparent red blood-vessels, and, doubtless, not without undergoing a loss; whilst another portion, traversing the less vascular parts of the retina, will mix with the rays reflected from the blood-vessels, and produce white light. But the green colour of the light actually emitted from the eyes of the animals in question, shows that these effects are only partial, as we might expect them to be. And neutralisation of coloured light, in either of the ways referred to, can only affect the light which has traversed the retina, so that, after making all allowance for its occurrence, the

[1] Catal. Mus. R.C.S., Lond., vol. iii., p. 163.

main conclusions urged in the preceding sections will remain unaltered.

The question then arises, may colour-blindness ever depend on such variations in the colour of the internal membranes of the eye as have been shown to occur? In reply to this question, I can refer to but one fact, and that does not favour the conclusion, that true colour-blindness can be occasioned in the way suggested. It is quite certain that Albinos are not necessarily colour-blind. In the very curious account of his own and his sister's albinism, furnished by Dr Sachs, there occurs the emphatic announcement,—"Leucaethiopes nec *achromatoblepes*, nec *acyanoblepes* sunt. Sibi quidem ipsi omnes colores, eosque non aliter ac ceteri plerique Homines, cernere atque discernere videntur."[1] Sachs's opinion is liable to the objection, that it is his own judgment upon himself, not unequivocally confirmed by a person of normal vision: and exception might further be taken to his conclusions, inasmuch as besides his albinism, his perception or conception of colours was singularly anomalous. Sachs was subject to what has since been called *hyperchromatopsy*, *i.e.*, a propensity, more or less constant, to attach the idea of colour, not only to physical objects, which, to ordinary vision, appear coloured, but likewise to things from which the majority of mankind generally abstract altogether the conception of colour. Thus, he imputed colours to the letters of the alphabet, the notes of the musical scale, the ordinary numerals, and the days of the week. In the alphabet, for example, *a* was red, *i* white, and *u* black. In the days of the week, Sunday was *white;* (as if, like a Roman, he regarded it *dies creta notandus*); Monday was *grey* (recalling our school-boys' *black* Monday); Wednesday was *yellow*.[2] From the observations, however, of Cornaz and Wartmann, it appears that this rare affection is not necessarily an accompaniment of albinism, and that examples of it occasionally occur in those whose vision is otherwise normal.[3]

It is unnecessary, however, to discuss the exact value of Sachs's conclusions concerning his freedom from colour-blindness, as Wartmann has put on record the examination of four youthful Albinos, three females and one male. Two of the girls and the boy were of one family, and the third girl was cousin to these three. All four, Wartmann tells us, "ne présentent aucun Daltonisme." He ascertained this by direct trials, and mentions specially, that they distinguished correctly the closely approximating shades of the same colour. They also perceived all the tints of the spectrum.[4]

[1] Hist. Nat. duorum Leucaethiopum auctoris ipsius et sororis ejus, à G. Sachs, M.D.—*Solisbaci*, 1812, p. 75, par. 150.

[2] Op. cit., p. 82, par. 160.

[3] See, in illustration of this Mr W. White Cooper's comments in the article "Vision," Cyclopædia of Anatomy and Physiology; and Wartmann's Paper, p. 43, referred to in the succeeding Note.

[4] Deuxième Mémoire sur le Daltonisme, par E. Wartmann. Genève, 1849, p. 42. I am indebted to Mr W. White Cooper, of London, for a knowledge of this Memoir, and for the use of one of the few copies of it which have reached

It thus appears that a total absence of pigment from the choroid, and a replacement of the dark surface found in ordinary human eyes by a brilliant red one, is not incompatible with a perception of colours, such as a skilful observer, like Wartmann, thoroughly alive to the existence of colour-blindness, could not distinguish from a purely normal perception. But the conditions of the Albino eye are very peculiar, and the small number of Albinos, and these very young, who were examined by Wartmann, cannot be considered as finally disposing of the question, Is the Albino vision of colour the same as that of the non-Albino eye? especially when the peculiarities of colour-vision exhibited by Sachs, the only adult, educated subject of albinism whose experience is fully on record, are taken into account.[1]

Nevertheless, I am not disposed to assert that colour-blindness, of the kind Dalton and his fellows exhibited, can be occasioned by such modifications in the colour of the membranes of the eye as I have drawn attention to. But an extreme chromatic equation, not always distinguishable in its practical manifestations from veritable colour-blindness, may certainly be occasioned by the varying condition of the membranes referred to, and on this account I have, in the introduction to this discussion, spoken of such manifestations as deserving to be ranked under a special chromatic theory of colour-blindness.

I close this section with the expression of the hope, that the colour of the membranes within the eye-ball will now be an object of more frequent and minute examination by physiologists and pathologists, than it has hitherto been. My friend, Dr Beddoe, has indirectly supplied much interesting information on this subject, in his little work recently published,[2] containing the results of an examination during life, of the colour of the eyes and hair of some 5000 of the Scottish people, representing nearly all the districts of their country. According to the observations of John Hunter, already quoted, in which physiologists generally concur, a dark choroid and dark hair go together, and *vice versa*. In the future enumeration, accordingly, of cases of colour-blindness, it is desirable that the colour of the hair should be recorded, as it cannot be expected or desired that the majority of the colour-blind should speedily become the subjects of pathological investigation. The colour of the iris generally, but

this country, where it is much less known than it deserves to be. Had I been aware of its existence at an earlier period, I should gladly have quoted from it; and I shall have occasion, in the sequel, to refer to it more fully. I infer, from its title, that it is a reprint from the Memoirs of 'La Société de Physique et d'Histoire Naturelle de Genève,' for 1848.

[1] I urge this the more that I learn from Wartmann's second Memoir, that the late Dr Cunier published cases "where several *dyschromatopsic* [colour-blind] females presented the greater number of the symptoms assigned by Beer and other oculists, to the absence of the black pigment of the choroid." These appear to have been colour-blind Albinos, but I cannot ascertain the particulars of their cases, which are recorded in "Annales d'Oculistique, t. 1, p. 490," a work of which only the later volumes are accessible in Edinburgh.

[2] A Contribution to Scottish Ethnology. By John Beddoe, B.A., M.D., 1853.

not invariably, resembles in shade that of the hair, and a hazel or pale golden iris has been thought to be an index of colour-blindness. Of the truth of this particular conclusion no proof has been given; but it is certain that the amount of dark pigment on the back of the iris (*uvea*), increases or diminishes in proportion to the general abundance of colouring matter tinting the choroid; and it would be highly interesting to know whether the fair-eyed and the dark-eyed—apart from colour-blindness—attach a different chromatic value to the same colour. The proverbial difference between the tints preferred for dress by blondes and brunettes, and the great fondness of the negro races for white and the primary colours, are probably *in part*, at least, related to differences in the colour of the choroid, to which that of the hair and of the iris is a clue. The hair is probably the more important external index of the chromatic condition of the choroid, especially where the hair differs in shade from the iris; but this is not certain; and even if it were, it will often be impossible, in the living human subject, to look at both, so that in all cases each should be examined, and the result recorded. I regret that I was not alive to this at an earlier period of my researches, so as to have noted the hair and eyes of all my colour-blind acquaintances. Like most other writers, however, on the false vision of colours, I have not had my attention prominently attracted by the dark or the fair monopolizing colour-blindness. Such observations as those of Dr Beddoe can alone settle this question, and would, in addition, throw light on other important problems.

CEREBRO-RETINAL THEORY OF COLOUR-BLINDNESS.

The second of the leading physical theories of colour-blindness refers the false perception of colours to the peculiar organization of the nervous apparatus of the eye, including so much of the brain as is essential to vision (*ante* p. 77.) It may be conveniently called the *cerebro-retinal* theory of colour-blindness.

Many more modifications occur in the various published versions of this theory than in the chromatic hypothesis which has been discussed. On the whole, however, they may be ranked in two divisions, and named the *cerebral* and *retinal* theories, according as the *brain* or the *retina* is held to be most concerned in the manifestation of abnormal vision. It is not intended, however, by such names to imply that the retina alone, or the brain alone, has been regarded as the sole seat of colour-blindness. On the other hand, in our ignorance of the full extent to which the brain is essential to vision in all its relations, it has been felt vain to speculate too nicely on the relative share which the nervous expansion within the eye, and those portions of the brain into which the optic nerve can be traced backwards, severally contribute to the vision of colour.

Of the cerebral theories of colour-vision, only one calls for special notice. According to phrenologists, the power of distinguishing

colours depends upon a particular part of the brain lying over the roof of the orbit, and, when largely developed, rendering one part of the superciliary ridge specially prominent. In the words of Mr Combe, "Observation proves that those individuals in whom the portion of the brain which is immediately above the eye, beneath the eyebrow, is largely developed, possess in a high degree the faculty of distinguishing colours."

The question whether a prominence in one part of the eyebrow characterizes those who have the power of readily distinguishing colours, and, conversely, whether a flatness or depression is found in the same region in those whose sense of colour is imperfect, plainly admits of settlement without discussing any portion of the metaphysics of phrenology. The thesis maintained by Mr Combe and other phrenologists is, that not only is a feeble normal perception of colours accompanied by a small development of the superciliary prominence which they term the organ of colour, but that this organ is still more decidedly depressed or absent in those who are colour-blind. In support of this conclusion, they have published accounts of several well-marked cases of colour-blindness, in which the organ of colour was defective or absent. Among the cases also which I have recorded, Dr K. and Mr R. have reported that they have been pronounced by phrenologists to have the same defect. Mr D. also informed me that the organ of colour was wanting in him.

The general result, however, of more extended inquiry has not been favourable to the phrenological conclusions. I have made no cranial examination myself of any of the cases of colour-blindness known to me, not from indifference to the matter, but because, as I must frankly confess, I am unable to distinguish such differences between the development of one superciliary ridge and another, as I find other observers declare themselves able to do; and I therefore give no opinion, founded on personal observation, on this question. There has been no want, however, of inquirers; and the general result, so far as my knowledge extends, has been the following:— Wartmann, in his first memoir, observes, "I must say that among the Daltonians whom I have examined, the organ in question (*i.e.*, of colour) was in general but little evident, except in two of them, in whom it was remarkably prominent."[1]

The late Lord Jeffrey was pronounced by phrenologists to have a feebly developed organ of colour.[2] He, however, was not only free from any trace of colour-blindness, but, as he has recorded himself, received great delight from the spectacle of brilliantly coloured objects, and had a remarkable power of matching colours from memory.[3]

Szokalski, who has had great experience in cases of colour-blindness, and agrees with phrenologists in the belief that there

[1] Taylor's Scientific Memoirs, 1846, p. 184.
[2] Combe's System of Phrenology, 3d Edition, p. 405.
[3] Op. cit., p. 406, and Edin. Rev., Nos. 88 and 89.

is a cerebral organ of vision, and that this is diminished in volume in the colour-blind, adds, notwithstanding, "We know well that phrenologists place the organ of colour in the middle of the superciliary arch; we have, however, examined scrupulously and with great pains many persons who have presented very decided depressions of this arch; but despite of the best wishes in the world, we could never discover in them any trace of chromato-pseudopsy."[1]

Mr W. White Cooper observes on this passage, "neither does our own experience support the theory of the phrenologists; in two well-marked Daltonians examined by us, the whole superciliary region was remarkably well developed."[2]

The whole of the observations referred to above were made on the head during life, and are open to the objection to which all such observations are liable, that they identify the internal development of the brain with the external configuration of the skull. This objection is specially pertinent in reference to the phrenological organs situated in the neighbourhood of the frontal sinus, and that it is not a speculative difficulty, can be shown by a very curious example which has not hitherto come before writers on this subject. At the *post-mortem* examination of Dalton's body, the following fact was observed, as stated to Dr Henry by Mr Joseph A. Ransome, Dalton's medical attendant, who made the examination; "Mr Bally (formerly assistant to the late Dr Spurzheim), was present, and took casts of several parts of the brain and the cavity of the skull. He pointed out a remarkable prominence on the frontal portion of the orbitar plates (which represents the phrenological site of the '*organ of colour*'), and the imperfect or deficient development of the convolution of the anterior lobes, which rested upon them. Of course, Mr Bally adopted this as the true explanation of the peculiarity of Dalton's vision; and we as witnesses (not only without faith in phrenology, but even opponents), are bound to record the fact."[3]

Here, then, according to the judgment of those present, there appeared a marked deficiency in that portion of the brain which phrenologists regard as the organ of colour, in the person of the most famous example of colour-blindness, and though he were not famous,

[1] Quoted by Mr W. White Cooper, Article *Vision*, Cyc. of Anat. and Physiol.

[2] Op. et loc. cit.

[3] Henry's Life of Dalton, p. 201. It seems proper to inform the reader, whether disposed to draw conclusions favourable or unfavourable to the phrenological explanation of colour-blindness, that Dalton died at the age of 78, seven years after an attack of paralysis, which permanently impaired the use of the right side, as well as the power of articulation, and the memory of words. Several slighter attacks succeeded in the intervening years, and the last proved fatal. Lesions of the brain, such as occur in cases of the kind, were found after death, the particulars of which will be found in the work quoted above. How far a diminution in volume, or apparent imperfect development of the anterior cerebral lobes, may have been connected with the advanced age, and repeated attacks of paralysis which Dalton had undergone, I will not pretend, even remotely, to determine, but the brain was certainly not in a normal condition at the time of the *post-mortem* examination.

his case would deserve record as the solitary one where the brain itself was examined. Something, as I have implied in a note, must be deducted from the value of this case on the ground of the effects which time and disease had produced upon an organ so liable to derangement as the brain. Let it be assumed, however, that no such deductions are called for, and then the truth I wish to dwell upon will be more fully appreciated, namely, that during life no phrenological sign of colour-blindness appeared on Dalton's forehead. Those who have seen him, or who are familiar with his busts or portraits, will be aware that his head, which remarkably resembled that of Sir Isaac Newton, was like it in exhibiting prominent eyebrows. The superciliary ridge in truth, projected very markedly so as to overhang the eyes. If any man would have been selected by phrenological signs as the possessor of an exquisite sense of colour, Dalton would have been. Yet assuredly, if Newton and Dalton had been contemporaries, and had simultaneously published and compared their descriptions of the colours of the rainbow, they must have been hopelessly perplexed to account for statements, so strangely conflicting, regarding a common object of vision.[1]

The doctrine, accordingly, that colour-blindness depends upon the absence of that portion of the anterior lobes of the brain in which phrenologists place their organ of colour, has not been substantiated. It may be quite true, nevertheless, that there is a part of the brain specially connected with the vision of colour, as we are quite certain that a part, and only a part, of this organ is essential to the integrity of vision in general. But the researches of physiologists do not, as yet at least, justify the conclusion that any portion of the brain so situated as to impress its form upon those parts of the skull which can be examined during life, is peculiarly related to the sense of sight; and I entertain no expectation of further investigation lending more justification to the phrenological hypothesis. Colour-blindness is, in the great majority of cases, only partial, and although I differ from most previous writers on this subject in regarding it as affecting the perception of the lighter and darker shades of all colours; still it has been abundantly shown that the greater number of the colour-blind do not mistake yellow or blue when full and well illuminated; nor have they any difficulty with white and black. If, then, an organ of colour is essential to the perception of blue and yellow, *ex. gr.* there seems no reason why the majority of the colour-blind should exhibit a deficiency of more

[1] I have not trusted to my own judgment in referring to Dalton's forehead, although I have seen him, and have examined a cast taken from his face after death, as well as many portraits of him. Dr Henry, to whom I referred the question, Had Dalton a prominent superciliary ridge? informed me in reply, that, unwilling to trust his memory on the matter, he had consulted a copy made by machinery from Chantrey's faithful bust, and found the eyebrows strongly marked in it as he remembered them to have been on the living head.

than about a third of the hypothetical organ of colour, unless it be contended that it is mainly serviceable in enabling us to perceive red. It appears vain, therefore, to expect to discover the existence of colour-blindness by so rude an external indication, as the prominence over a small area, of one of the plates of the skull. But it is assuredly desirable that observations should be multiplied on this point, and that the condition of the brain in the colour-blind should be carefully noted.

I do not discuss the *Retinal* theories of colour-blindness minutely, for the greater number of them are either mere descriptions of this affection of vision in the terms of a hypothesis which regards the retina as its seat, or they are speculations which connect such an assumption with views regarding the organization of the membrane in question, which neither admit of being confirmed or refuted. Many of those views are exceedingly ingenious, and well worth the attention of students of the theory of vision. They will be found fully and impartially discussed in Wartmann's Memoirs. But they lie too far beyond the scope of my present inquiry, which mainly deals with what is physically demonstrable in the phenomena of colour-blindness to justify their discussion here, especially as they have little bearing on the practical questions connected with this affection of vision. I shall content myself, accordingly, with explaining the theory published by Wartmann in his second memoir, and with publishing a very interesting speculation on the same subject, for which I am indebted to my friend Professor Kelland.

"I admit," says Wartmann, "with Harvey, Young, Jüngken, Müller, and others, that its seat is in the retina, and I think it is produced by an abnormal state of this nervous expansion of such a sort that it reacts similarly under two or more different coloured radiations. If the vibration (*ébranlement*) caused by a red ray is identical with that which a green ray produces, there will be confusion of these colours. This theory is independent of every system destined to explain light."[1]

Wartmann then proceeds to illustrate his view more fully by the analogy of sonorous bodies. If, as he observes, a series of elastic surfaces unalterable by atmospheric variations, and each of which gives out a different musical tone when placed in communication with a sounding body, is arranged together close to a musical instrument, frequently in use, at the end of some days it will be found that the note which at first threw into vibration only one of the elastic surfaces, will by and by produce the same effect upon a second, and thereafter upon several more. "Thus," continues he, "the elements of this system will have become modified in their facility of vibration, and by also resounding easily under the influence

[1] Deuxième Mémoire, p. 46.

of different tones, they will resemble the retina of a Daltonian who confounds different colours." An experiment is then described, in which the panes of a closed window which at first vibrated only under the influence of certain notes or tones of a piano in the window-recess, were by prolonged daily use of the instrument thrown into vibration by several additional tones to which at first they did not respond; and conversely acquired their original indifference to these when the piano was left unused for six months. According to this view, the retina, to use Wartmann's own words, "is in a state *analogous* to that of an elastic system which two or more musical tones throw into resonance with equal ease."[1]

The theory of Professor Kelland, which I subjoin, was first explained orally to the Royal Scottish Society of Arts, in April 1853, on the occasion of my reading a communication on Colour-Blindness, and was shortly afterwards reduced to writing at my request.[2]

"AN ATTEMPT TO EXPLAIN CHROMATOPSEUDOPSIS. By the Rev. PHILIP KELLAND, Professor of Mathematics, University of Edinburgh.

"On the undulatory theory, light is due to vibrations, and difference of colour, like difference of pitch in music depends on nothing else than the period of pulsation, or the time occupied by a vibrating particle in performing its oscillation. The whole scale of colours is comprehended in something like the same limits as the octave in music—the extreme vibrations being performed in times which are very nearly in the proportion of two to one. The sensation of a given colour is therefore due to the reception by the retina of pulsations of a given period. In what way the retina performs its functions we do not precisely know. As the instrument in conveying pulsations, it may be presumed itself to vibrate agreeably to their period. We shall, accordingly, regard it in its normal state, as a vibrating system capable of responding to pulsations of every period, within certain limits, and of conveying to the mind the sensation which we term colour appropriate to each period. But in other states of the eye, this appears incapable of being effected. The retina, for instance, vibrates more readily in accordance with one period of pulsation than with another. Thus one eye may be very well disposed to respond to

[1] Op. cit., p. 48. Wartmann's Deuxième Mémoire, from which these views are taken, was read to the Physical Society of Geneva, on 9th Oct. 1848; but from a reference in that memoir to a second edition of his *first* paper on colour-blindness, contained in la Bibliothèque Universelle, the publication of the theory referred to goes back to June or July 1845. (Deuxième Mémoire, pp. 2 and 45.)

[2] As a certain resemblance occurs between the theories of Wartmann and Kelland, it is proper to mention that the latter was not aware of the former's opinions till the autumn of 1854, when, on first becoming myself acquainted with Wartmann's "Deuxième Mémoire," I showed it to Professor Kelland.

vibrations of the period of the yellow, so as to be powerfully affected by it; another may be almost insensible to the red, so as to be scarcely able to discern faint objects of that colour. This constitutes one form of chromatopseudopsis. But a more remarkable form is that in which the powerful complementary colours produce the same impression on the mind. This would appear to be owing to the facility possessed by the retina for starting into vibrations of every period, when excited by those of one only, just as a musical pipe or string gives all the notes of the chord at the same time, or as the different strings of a harp vibrate when only one has been struck. The retina, in this case, may be compared to a piano, or rather to one octave of a piano without dampers; the sound of one note causes all the others to vibrate at the same time, but not with equal intensity; the centre note between the note struck and its octave being most powerfully affected. Assuming this analogy to be correct, we should expect to find that, in a retina so constituted, every colour would be mixed more or less with its complement. In the case of green or red, the complementary red or green respectively is of equal intensity with the original, and consequently the same impression may be produced on the mind whether the direct red raises up its complementary green or *vice versa*. On the other hand, the powerful yellow having as its complement the weak purple, we should not expect that it would be matter of indifference which is the direct agent and which the subjective impression. Accordingly, we find many eyes unable to distinguish green from red-but few apt to confound yellow with purple.

"To eyes constituted as I have supposed, those combinations of colour which by contrast produce the most powerful and pleasing impressions on others ought to be rather unpleasing, since contrast of colour in the one is replaced by difference of tone in the other. We have reason to believe that a similar phenomenon occurs relative to sound: we know, at least, that many persons are totally insensible to the *pleasurable* sensation of melody, but whether or not such persons experience a different impression of pitch from that which affects ordinary ears, has not probably been ascertained. Persons have been known destitute of the power of distingnishing one air from another, provided the rhythm of both were the same, but whether this has arisen from mere dulness of discrimination of tones, or from a positive similarity of impression from tones which, to ordinary ears are very different, has not, perhaps, been well investigated. It is not impossible that the latter hypothesis is correct, at least it involves interesting matter for further inquiry."

The ingenious theories of the professors of Geneva and Edinburgh will be acknowledged by all to assist us in forming a clear and vivid conception of what may be the condition of the colour-blind retina, and they very probably furnish not only a picture of its condition, but to some extent a fac-simile of its mode of abnormal action. Kelland's theory is the more complete of the two, inas-

much as it both provides an explanation of that simple insensibility to a colour, such as red, which we do no more than name when we call it colour-blindness; and also of that confusion of colours with each other, which is likewise simply named when it is called, Chromatopseudopsis: whereas Wartmann's theory only accounts for the latter. In the preceding sections, however, of this paper, it has been shown that there is a positive insensibility of the retina in many persons to red light, which excites neither the sensation of luminosity nor of colour; and further, that the dark shades of all colours, primary, secondary, or mixed, are not distinguished by the colour-blind from black, and that the very light shades are not distinguished from white. Apart thus from the tendency to confound colours with each other, there is, on the part of the colour-blind, a positive inability to perceive certain of these. Their vision of such colours is not false or confused; they have no vision of them at all. The condition of a retina thus insensitive to colour appears more like that of a vibrating sonorous body which cannot be made to sound by strokes, or impulses of a certain intensity, than one which passes into vibration if any other elastic substance in its neighbourhood begins to vibrate.

An addition, therefore, must be made to Wartmann's hypothesis, and whether we adopt Kelland's theory, or not, we seem to be fully entitled to affirm that the cerebro-retinal apparatus of vision in the colour-blind is, either through congenital defect, or subsequent morbid change, unendowed with that sensitiveness to colorific impressions which it possesses in those whose vision is normal. It is probably the retina that is the chief seat of this diminished sensibility to colour, and the simpler form of colour-blindness might fitly enough be called *chromatic amaurosis*.

VI.—ADVANTAGES AND DISADVANTAGES OF COLOUR-BLINDNESS; ITS PREVENTION AND CURE.

In discussing the evils (which must take precedence of the advantages) of colour-blindness, I do not propose to enumerate minutely the disadvantages which it entails on its subjects, but to confine myself to certain of the more formidable difficulties or dangers in which it involves both themselves and others who trust to their judgment in reference to colours.

It will be convenient to discuss the subject under three divisions.

1. *Does colour-blindness admit of cure?*
2. *Does it admit of temporary palliation or correction?*
3. *For what professions is colour-blindness a disqualification?*

1. *Does colour-blindness admit of cure?*

Congenital colour-blindness is certainly incurable; and the case of Mr B. (*ante* p. 39) shows that when induced by injury or disease, it may become as irremediable as if it had been an inherited

peculiarity; but certain forms of this affection are transitory and admit of cure.

Mackenzie, Wartmann, Ruete, Cunier, Boys de Loury, W. Cooper, and others, have recorded cases of temporary colour-blindness resulting from "congestion, hepatic derangement, and dyspepsia,"[1] which disappeared under appropriate treatment. Such cases are probably very common, and appear to exhibit the same phenomena as congenital cases, from which, indeed, they differ only in being temporary and curable.

An opposite opinion, so far as permanent colour-blindness is concerned, has been expressed by Dr Pliny Earle (himself a member of a family in which seventeen cases of this affection of vision have occurred), but, so far as appears, he only contends that "a succession of years modifies the Daltonism of the same individual," without stating in what way, and to what extent, advancing years induce a change.[2]

So far as I can ascertain from the examination of the cases of colour-blindness within my reach, the amount of modification in the perception of colours, induced by age, is inappreciable, even though no allowance be made for that alteration in all the powers of vision which time produces on every eye. Thus: Dalton was certainly as colour-blind at the Oxford meeting of the British Association in 1832, where he compared the colour of his scarlet D. C. L. gown to that of the leaves of trees, as in 1792 when he first discovered his colour-blindness; nor did any change, so far as his associates were aware, occur in his perceptions of colour up to his death in 1844. Mr Milne of Edinburgh is still (October 1854), as colour-blind as he was when Mr Combe described his case thirty years ago,[3] and as he had been for years before his case was described. Prof. N., whose case I have referred to previously (*ante* p. 33) was examined as to his perception of colour, some thirty years since, by Sir David Brewster, who has recorded his case. He writes me recently, "I am under an impression that some change in appreciating colours took place in my eye between childhood and youth. As a child, red gooseberries seemed to me altogether blue, so far as I remember; latterly I have observed what I fancy red in this variety of fruit:" and again, "I suppose sometimes that I can distinguish red in some objects, but probably this is from knowing that they are usually of this colour:" but he adds, "at any rate, I am quite sure I should make a dangerous railway signalman, as I most certainly would not know a red flag from a green one." This gentleman further states, in answer to some queries, that *pink* still appears to him by daylight *blue*, and by gaslight *green*,

[1] Wartmann, 2de Mémoire, p. 20. W. W. Cooper, article Vision, Cycl. of An. and Phys.

[2] *Amer. Journ. of Med. Sciences*, 1845, quoted in Wartmann's 2de Mémoire, p. 45.

[3] System of Phrenology, First Ed., Art. Colouring.

and that he continues to confound carmine-red by daylight with blue. There plainly has been nothing deserving the name of improvement in his case.

Lastly, the Countess of D., whose case has been described previously, as it showed itself in 1853, has not appreciably altered in her colour-blindness since its peculiarities were described by Wollaston many years ago.

Those cases may suffice to illustrate the permanency of this affection of vision; but they are not singular. Among my colour-blind acquaintances there are probably none who would not sacrifice a great deal to see perfectly; and nearly all have endeavoured to cure themselves of their visual idiosynerasy, but not one reports a cure, and the best educated and most observant among them are the most decided in declaring that they have given up all hopes of amendment.

It is difficult to convince many that this conclusion is a just one. Those whose own sense of colour is delicate, and who are led by taste or profession to live much among coloured objects, are slow to believe that any eye can be so peculiar in its endowment, as to make the blunders which the colour-blind do, even in reference to what they would call "a staring" red or green. Such colourists insist, that carelessness, indifference, or improper education, lies at the bottom of the mistakes which the "supposed" colour-blind make, and profess themselves willing to undertake their cure; of which, however, they record no case.

I have no doubt that a certain amount of improvement in the judgment of colours may be induced in most colour-blind persons, who have not attempted self-education in reference to their chromatic perceptions, or been unconsciously led to study colours. For as they generally perceive blue and yellow without difficulty, and distinguish, within certain limits, the tints and shades of many colours, their perception of those must, and certainly does, admit of improvement by education. But this improvement does not lessen their tendency to confound certain colours and certain tints and shades. When we find an engraver who, for the greater part of his life has been gazing all day at paintings, purchasing a red window curtain for a green one: a tailor, whose eye has been for hours daily fixed on cloths of very varied colours, matching green tape with scarlet linen, at the risk of losing his situation: an experienced field-geologist compelled, when surveying a red sandstone district, to take a companion with him, to point out where grass ends and sandstone begins: and a teacher of chemistry evading, as much as possible, the questions of his pupils concerning the colours of bodies; we cannot doubt that after education has done all that it can towards developing the sense of colour in the colour-blind, they remain as helplessly prone to make their characteristic blunders as before. A crowning example of this has recently presented itself to me. In the establishment of a painter and glass-stainer, who is an obstinate disbeliever in the existence of colour-blindness, my attention was

recently directed by his fellow-workmen to a youth, who had been set to re-paint the devices on the shafts of a sheaf of arrows. These devices, consisting of alternate circles of red and green, had not been effaced, but only dulled; yet the painter executed his task by painting all the *red* rings *green*, and all the *green* rings *red*. The case was remarkable for the direct reversal of the colours in question, and this by one who had them before him to compare, both on his palette and on the arrows. Yet the party who committed this mistake was an excellent draughtsman, much esteemed by his master, and surrounded at his daily work by splendid specimens of stained glass. The mistake which he made soon ceased to be a solitary one, for his fellow-workmen having since its occurrence, put him to the test, found him uncertain in his judgments of many colours, and on examining him I found him commit the characteristic errors of the colour-blind. Here, then, was the possessor of an educated colour-blind eye, making such mistakes, as no normal-eyed person, however uneducated his power of vision might be, could or would make.

Education, then, can do nothing towards curing colour-blindness, nor in truth can anything else. Dr Trinchinetti, an Italian physician, believing that the seat of this affection of vision is the crystalline lens, gravely proposes its extraction, as a radical cure of the evil! I would not refer to this proposal, which requires no formal condemnation, were it not that I have met with a case which appears to prove (what needed, however, no proof) that colour-blindness would survive removal of the crystalline lens.

I have recently been visited by Mr J., who has had both lenses removed for cataract. The one lens was removed some years ago, by Dr James Duncan of Edinburgh, the other recently by Dr Macmurdo of London. His vision is good, and his ordinary perception of colours normal, but in reply to some casual questions on these points, he surprised me by stating that, whilst suffering, on a recent occasion, from vertigo (to occasional attacks of which he is subject), he was astonished to perceive that all the persons he met in the street were dressed in *green*, "recalling," as he said, "the descriptions of Robin Hood's men." This false perception continued for some hours, and has since on several occasions returned. Here a susceptibility to colour-blindness remained, though the lenses were gone, and had the affection been congenital, instead of temporary, we may justly infer that it would have equally remained.

2. *Does colour-blindness admit of temporary palliation or correction?*

As colour-blindness is certainly incurable, the possibility of palliating or temporarily remedying it becomes an important question, and the prospect of a satisfactory answer is far from hopeless. I shall discuss, first, the methods of assisting the colour-blind which have been proposed by others, and afterwards suggest certain which have occurred to myself.

[1] Wartmann, 2de Mémoire, p. 38.

1. *Comparison of doubtful with known colours.*—A means of guarding against mistakes, relative to colours, which is unquestionably of some service to the colour-blind, is the reference of doubtful hues to a chromatic scale, accurately tinted and named. But this means of correcting error soon finds its limit, as the mismatchings of red with green, olive with brown, and purple with blue, characteristically made by the colour-blind (although both colours are presented to the eye together), are sufficient to show. And, in truth, I strongly suspect that the first chromatic judgments of the colour-blind are often more trustworthy than their later ones, and that in general they are at least of equal value. This remark specially applies to the confusion of red with green, where each so rapidly calls up its complementary to the colour-blind eye, that it is quickly disabled from determining which was the primary and which its complement.

2. *Protracted gazing on coloured bodies.*—Szokalski and Seebeck have recommended, as a means of ameliorating the condition of the colour-blind, their steady gazing, first, on a coloured surface, and then on a white or black one,[1] but from what has been stated in the preceding section, and previously in reference to the general education of the colour-blind, this proposal seems of no value; nor is any proof offered that it has been of service.

3. *Use of coloured transparent media.*— It has occurred to various observers that assistance might be afforded to the colour-blind by causing them to look through coloured transparent media at the colours which were doubtful to them. Wartmann observes on this point: "There exists a very easy means of rectifying, to a certain extent, the error of the appellation of colour. This means consists in examining coloured objects through a transparent medium, as a glass or a liquid of a certain known tint. Suppose this tint red; the impression of a green body and of a red body the same at first to the naked eye, will become manifestly distinguished by the use of the transparent screen. This method appears to have been practised for the first time by Professor Seebeck, the father, towards the year 1817. Nothing can equal the surprise of a Daltonian when the errors which he commits every day in the appreciation of colours are thus disclosed to him. Unhappily the tint of the coloured glasses and their number cannot be prescribed in advance; the impossibility of a rigorous classification of the innumerable varieties of Daltonism obliges us to choose them *à posteriori* for each particular case. We may add, that their employment only remedies mistakes in the specific nature of colours, and leaves in general those which apply to one and the same tint."[2] Dr Steebach has carried out this proposal the length of recommending the use of coloured spectacles.[3] Trinchinetti advises that the glasses should be of the colour which is the comple-

[1] Wartmann, 2de Mémoire, p. 50.
[2] Taylor's Scientific Memoirs, 1846, p. 185.
[3] Wartmann, 2de Mém., p. 50.

ment of that liable to be seen falsely.[1] To this Wartmann justly objects, because "Daltonians do not judge correctly of complementary colours;" but his own proposal to employ transparent media of other colours is liable to as great objections.

I am far from wishing to affirm that a colour-blind person may not be aided in correcting his chromatic errors by such a use of coloured glasses as Seebeck and Wartmann recommend, but after many trials with my colour-blind acquaintances I have found none who could turn the suggestion to practical account. My trials have been chiefly made upon those who confounded red with green, to whom Wartmann, in illustrating the use of coloured transparent media, specially refers, but I have met with no success. Nor does this surprise me; I should have been surprised had it been otherwise. How could it be expected that an eye to which the same glass seems sometimes red, sometimes green, should be assisted in distinguishing between opaque bodies of these two colours by looking through the glass? The colour of the glass is not a constant quantity for the colour-blind, any more than the colour of the bodies looked at through the glass. If the last were actually red, and appeared of this tint to a colour-blind eye looking through it at red, the latter, we may presume, would appear redder; but if the glass appeared green whilst looking through it at red, this would probably also appear green, for the same cause (whatever it be) which falsified the colour of the transparent medium, would falsify that of the opaque one. The only coloured transparent media which can be expected to serve the colour-blind are such as do not alter in apparent colour to their eyes, and the choice must therefore be restricted to those which are blue or yellow. I shall presently seek to show that yellow media promise to be serviceable, but the consideration of this belongs to another place.

4. *Employment of touch to distinguish colours.*—Wartmann has pointed out the interesting fact, that in one well marked case, a colour-blind person "corrected by the help of touch, a part of the erroneous judgments which he formed regarding colours,"[2] and he had reason to believe that several other "Daltonians" were similarly endowed.

The first example of colour-blindness I encountered (Case II., Mr P.) possessed the power in question to some extent, and I found it useless to show him the same pieces of coloured paper more than once, as he recognised them the second time, but not, as he distinctly declared, in virtue of the coloured impression they made on his eye. It was only in part, however, by touch that he effected this recognition, for slight differences in shape, accidental rough points, folds, wrinkles, and the like, caught his quick eye, and assisted him in reaching his conclusions. It seems to me exceedingly probable that this gentleman, whose sense of touch was prac-

[1] Ibid, p. 39.

[2] 2de Mémoire, p. 35.

tised and delicate, could have taught himself to detect by means of it differences between pieces of paper, cloth, linen, silk, and the like, dyed with different substances. The physical properties of pigments are sufficiently diverse, to alter in different ways the surfaces or substances which they colour. Wools, *ex. gr.*, dyed with certain compounds are much harsher to the touch than those dyed with others; the mineral pigments, such as Prussian blue, or chromate of lead, in general producing rougher surfaces than the organic dyes, such as indigo. A wool dyed with a mineral green might thus be distinguished by the touch, from one dyed with a vegetable red, although the colour-blind eye could detect no difference between their tints.

These conclusions are strengthened by a consideration of the fact, that even among those who are totally blind, examples occasionally occur of a power to distinguish colours by the touch.[1] The fact has been denied. But many of my readers must have seen the power in question exercised by a blind man in Stirling, whom I have frequently conversed with in my boyhood. He was regarded as one of the celebrities of the place, and was brought to strangers to earn a small fee, by telling the colour of their dresses by feeling them. This I have seen him do with men's dresses promptly and correctly.[2]

It seems quite possible accordingly, that colour-blind dyers, weavers, clothiers, and other workers among textile fabrics, may use their fingers to correct the errors of their eyes; and further, that the keen vision which (colours apart) they generally possess may, acting in unison with touch, turn to account those superficial, interstitial, and molecular differences which are the concomitants of

[1] Wartmann, 2*de Mémoire*, p. 36, gives a list of references to the published cases, amounting to some three, but thinks the existence of a tactile discrimination of colours not yet sufficiently established.

[2] Alexander Lyon, the party referred to in the text, familiarly known in Stirling as Blind Alick, was born in 1761, and died in 1836. A sketch of him is in existence from the pencil of George Harvey. He lost his sight in early infancy, and grew up untutored till he was eighteen years old, when the indications which he displayed of a very retentive memory, led to his being sent to school, through the interference of some benevolent friends. Here he acquired an acquaintance, believed to be complete, with the contents of the Bible, through hearing it read, verse by verse, by his schoolfellows; and in after life he could repeat any portion of it on a moment's warning. His knowledge in this respect was often tested, but was never known to fail. It was the fruit solely of a powerful memory, exercised upon the only book which he had the opportunity of hearing largely read in his early days, and did not imply any regard for its precepts, of which his life was a daily contradiction. So far as I can learn, he acquired the power of distinguishing colours by manipulating the dresses of his schoolfellows, as a means of distinguishing them from each other, when they tried to deceive him as to their identity, by using feigned voices. It does not appear that "he could indicate the colours of silk or cotton fabrics by touching them," as I learn from Mr Shirra, an intelligent draper in Stirling, who knew Blind Alick well.

different colours, in consequence of these inhering in different chemical compounds.[1]

In addition to the methods of mitigating colour-blindness which have now been discussed, I suggest the two following, the first of which, at least, is probably of more importance than any as yet made known to us.

1. *Substitution of artificial light for daylight in the examination of colours.*—The very striking difference between the aspect of certain colours to many of the colour-blind by daylight and artificial light, has been so fully referred to previously, that here I only discuss the practical application of the fact. The colours whose aspect varies most, are red (including crimson and scarlet) as contrasted with green; and pink, crimson, and other tints or shades of purple (especially red-purple), as contrasted with blue.

It is only some among the colour-blind who report themselves as seeing colours thus differently by different lights. But the number thus circumstanced is large, and the conclusion to which Dalton came, that there was much less discrepance between the judgments on colours of the colour-blind and of the normal-eyed, by candlelight, than by daylight, probably admits of wide application.

It is at least certain, that to very many an alteration in the quality of the light by which colours are regarded, causes these, as Dalton expressed it, to be "astonishingly changed." Supposed greens become by candlelight, reds; and blues are turned into pinks and crimsons. The contrast in appearance under the opposite illuminations is so great, that among the cases of colour-blindness which I have recorded, there are as many as six persons who have discovered that they could mitigate their peculiarity of vision by the employment of artificial light. Thus, Mr N., Prof. Y., and Dr E., have resorted to candlelight as a means of increasing their enjoyment of flowers, which, if crimson, appeared, when seen by it, much richer in colour than by daylight. Dr Y. has discovered that by

[1] Since writing the above, I have received the following communication from Mr Shirra, referred to in the preceding note. It supplies a confirmation of the conclusions in the text all the more valuable, that it was written in total ignorance of my opinions, and not in answer to any queries.

"I have heard of a woman, blind from her infancy, residing in Cambusbarns, who practised the occupation of a 'pirn-filler' (that is winding yarn on bobbins). Her sense of feeling enabled her easily to judge of the different sorts she was engaged with. If she were winding blue, and had finished one spindle, she would lay her hand on the next spindle, and could tell easily whether it was blue, green, purple, scarlet, or black. White she distinguished by her sense of smell, it being 'smeekit,' or fumigated with sulphur.

"I have heard that practical dyers are able to distinguish coloured yarns by the sense of touch, as well as the sense of sight, some peculiarity being imparted to the wool by the combination of substances used in dyeing, which gives it a peculiar character, sufficient to be known by mere contact."

It will be seen that wool alone is referred to in this statement. The colours of linen, cotton, silk, velvet, and the other fine-thread fabrics are plainly much less easily detected by touch than those on wool.

gaslight he can profit by chromatic distinctions, which are lost upon him by day. Mr R. can recognise, by lamplight, reds, which he mistakes for greens in the sun; and most striking of all, Mr S.'s friend (*ante* p. 34), who deals in coloured goods, has long been in the habit of appealing to a gas-flame in a dark room, to decide between scarlet and green, and crimson and blue. Those cases are sufficient to show that every colour-blind person may find it worth while to try the effect of artificial light in correcting his false visual perceptions.

What quality of light is best fitted to secure this correction remains to be determined, and an inquiry into the matter could not fail to supply much interesting information. From a few trials, I feel satisfied that the whiter and more intensely luminous artificial lights, such as the lime-ball and the electric charcoal light, induce the same confusion in the perception of colours as sunlight does.

Between the ordinary artificial lights, there is not apparently an appreciable difference, but candlelight alone, has been specially examined. Dalton ascertained that in the prismatic image of a candle-flame, the red extremity was much more vivid than that of the solar spectrum, and from the mode in which he refers to the candle spectrum, it seems certain that there was no such dark shade, or dimly illuminated band at its less refrangible end, as there was generally to his eye in the spectrum of the sun.

It should thus seem that to the colour-blind (in so far, at least, as they are represented by Dalton), the red rays of a candle-flame are visible, to an extent those of the sun are not, and in consequence red bodies are much less liable to be considered green; and pink, or crimson bodies, to be considered blue by candlelight than by daylight.

In speculating on the cause of this difference, with a view to its practical application, we cannot fail to recognise as chiefly important, the feeble intensity of candlelight as compared with that of sunlight, and the unlike ratios in which the coloured rays are distributed in the two kinds of light. So far as luminous intensity is concerned, the difference is immense, and as one peculiarity of the colour-blind eye is to see no colour in very lightly tinted bodies, *i.e.*, where much uncoloured light simultaneously falls upon the retina; and another is to perceive form and outline by very faint light, we may attribute in part the improved vision of the colour-blind by a candle, lamp, or gas-flame, to its feeble intensity compared with sunlight. It is plain, however, from the case of Mr N. (*ante* p. 29), that if the intensity of the light fall below a certain point, then the reds which were formerly seen, change into black, or become totally invisible. There is a practical limit thus set (varying no doubt with each eye), to the employment of faint light as a means of assisting the colour-blind.

It is to the chromatic qualities, however, more than to the feebler luminosity of artificial light, that we are probably to look for the

service which it renders those whose vision of colours is abnormal; for it does not appear (though perhaps the matter has not been sufficiently investigated) that there is any degree of intensity of solar light by which they make fewer mistakes than by full daylight; whilst, on the other hand, it has been fully shown that in twilight, even the normal eye betrays, in a minor degree, that blindness to red which is so characteristic of chromatopseudopsis.[1]

The colour of ordinary artificial light is sensibly different from that of daylight, compared with which it is yellow or orange; in other words the proportion of blue rays is smaller, and of yellow and red rays larger than in daylight. It seems probable, accordingly, that the preponderance in artificial flames of yellow light to which the colour-blind eye is keenly sensitive is a great cause of its better vision by such flames; but the presence in these of red rays which impress the abnormal organ of vision, as the red light of the sunbeam does not, must also largely contribute to the improved perception of colours. There must also be some proportion of red and yellow rays, in other words some quality of artificial light, best fitted to approximate to normality, the vision of the colour-blind. That in a candle we have this quality of light at a maximum is matter of surmise, and experiment alone can show among the artificial lights in ordinary use which approaches most nearly to it. The colour-blind could largely assist themselves by comparing their arrangements of coloured objects by different flames with a settled chromatic standard; and others could assist them by noting what colours they saw in the prismatic spectra of such flames. I have but one fact to mention in reference to this question. In the course of the trials made along with Professor Kelland on the visibility of the red end of the solar spectrum to the colour-blind, the opportunity was taken to test the vision of those present by a soda-flame, fed with oxygen, and made to illuminate wall papers of very varied colours. To those regarding themselves as normal-eyed, these became all undistinguishable greys, whilst Dr Y. and T. R. saw, as they declared, many colours, and pointed out two sectors of a seven-tinted circle as *green:* the one was green, the other red, so that they seemed to see colours at least as well by the soda-flame as by daylight.[2]

[1] Very bright and very faint light both diminish the sensitiveness of the colour-blind eye *to colour*, and therefore there must be a point of medium luminous intensity, where colours are best seen by it; but as the reports of cases of colour-blindness, in effect record the sum or mean of the experience of its subjects under all ordinary intensities of light, and register their most perfect judgments, it is plain that the difference between their best and worst decisions on colours, by light not extremely bright or faint is small; not greater, certainly, than that between the similar decisions of those whose vision is normal.

[2] A point of much interest in connection with this subject, but on which I can communicate nothing certain, is the extent to which the substance or texture of a coloured body, and the nature of the dye, affect its relation to

It is not probable, however, that the different colour and lesser luminous intensity of artificial light, are the only causes of its usefulness to the colour-blind. Much of this may depend on the different amount and intensity of the thermic and actinic forces in light from different sources, which assuredly vary immensely, and, as yet, have been imperfectly measured in most cases.

Further, two flames may have the same colour, and yet contain rays of very different refrangibilities. Thus the extra-spectral (or fluorescent) rays of Mr Stokes are greatly more abundant in some blue flames than in others (as they also vary in colourless flames), and two of those which to the ordinary observer appear identical, will, nevertheless, affect the eye (normal or abnormal) very differently, for, whatever theory of light we adopt, we must suppose that rays so unlike in their refrangibility, as the least refrangible blue of the visible solar spectrum, and the most refrangible blue of the extraspectral space make a different impression on the retina. The same remark applies to rays of other colours, and trial can alone decide how their distribution in a flame affects its influence on the colour-blind.

2. *Employment of yellow or orange transparent media to reduce daylight to the quality of ordinary artificial light.*—If artificial light assists the colour-blind in distinguishing colours, it should seem possible to correct their daylight chromatic errors, by conferring upon the light of the sun the properties (whatever they are) which enable artificial light to restore colour-vision to the colour-blind.

It seemed possible to effect this to some extent by passing daylight through yellow or orange media, and, accordingly, I obtained four pieces of glass stained with oxide of silver, and transmitting a pale yellow or orange light. They are referred to in the sequel as 1, 2, 3, and 4, being numbered according to their intensity of colour from the palest to the deepest. Two of them, 3 and 4, appeared yellow when looked through, but reflected from one surface a bluish-green light. These glasses, as will presently appear, proved of most service to the colour-blind.[1]

solar and artificial light as seen by the colour-blind. From what we know of normal vision, however, we may infer that silk and wool, *ex. gr.* of the same colour by daylight, will not necessarily, to their eyes, undergo the same kind and amount of change by candlelight. Thus, green silks and wools, which by daylight match very well in the estimation of the normal-eyed, often prove very indifferent matches by gaslight, owing partly, doubtless, to the difference of textile arrangement, partly to the difference of dye. I have recently been shown a lilac silk ribbon which to those (all of normal vision) who have seen it by daylight, appears to match closely with a lilac worsted. By gaslight, however, the latter becomes a cold grey, harshly contrasting with the silk which appears less brilliant, but otherwise little altered in tint. The colour-blind, we may be certain, have similar experiences, and we must not wonder if artificial light assists them more in seeing certain coloured stuffs than others.

[1] Mr Stokes refers the twofold colour of silver-stained glasses almost entirely to a *false* internal dispersion of light, and not to that true dispersion which he has named *fluorescence* (*On the Change of Refrangibility of Light. By G.*

Specimens of the four glasses were sent to Professor Y., Mr R., and to the colour-blind friend of Mr S. (*ante* p. 34.) Professor Y. derived no benefit from them; Mr R. found two of the falsely fluorescent ones of some use, and they were markedly serviceable to Mr S.'s friend.

Mr R. writes,—"I have delayed replying to your letter until I could give your experiments a fair and equitable trial. The glasses (all of them indeed) deepen or rather brighten the reds, but do not affect the greens so much. I can distinguish the reds by the aid of the glasses much better than I can the greens."

In a second letter he adds,—"Yesterday and to-day being very bright days, I have tried a series of experiments with the yellow glasses, and in all cases found No. 4, the most decided and certain in its results. No. 4, you will perhaps recollect, is a combination of two colours, one on each side of the glass. This gave a decided and very marked difference between red and green. Scarlets it made very bright and light, while crimsons were made decidedly red and fiery."

From Mr S. I received the following statement written by the party (*ante* p. 34), who was in the practice of resorting to a room containing a gaslight to distinguish between scarlet and green, and crimson and blue. "With the glass marked 4, I can see bright colours nearly as well as by lamplight, so that I can see the same difference between green and scarlet, and crimson and blue, as by artificial light, but it being rather dull I cannot see any but very bright colours. With No. 3 I can tell which is green, but not quite so well as with 4; Nos. 1 and 2 are of very little use."

Three additional pieces of glass, all to some extent falsely fluorescent, but paler in tint than No. 4, were sent, and were thus reported on:—

"I find the last three pieces of glass answer admirably, as they are clear, and show the colours almost exactly the same as they appear to me by lamplight, so that I can easily see the difference in most bright colours. . . . .

"All three of the pieces show a difference sufficient for me to know green, but No. 3 makes green look nearly black, while red looks brighter."

It will be seen from those statements that there is a prospect of success from the use, by the colour-blind, of glasses tinged yellow or orange, or of window-screens of these colours for rooms in which coloured things are to be examined; how far the false dispersion of the glass affects its utility I cannot determine.

Stokes, M.A., Phil. Trans. 1852; *and R. Hunt's Researches on Light, 2d edit.* 1854, *p.* 312); but the latter phenomenon was displayed to some extent by the glasses alluded to in the text, which were coloured throughout their entire thickness. The mass of the glass owes its tint to a silicate of the oxide of silver which becomes wholly or partially reduced to the metallic state at one surface during the process of staining, rather as an unavoidable result, than as a thing aimed at by the stainer.

I have not included the proposal just discussed, in the consideration of the suggested use of coloured glasses by other writers, because it was not the chromatic characters of yellow transparent media which led me to suggest them, but their power to confer upon daylight sent through them, certain of the properties of artificial light, as this affects the colour-blind eye.

That the colour of the modified light is one cause of its action on the eye cannot be questioned, and Sir David Brewster's opinion that yellow light has a special exciting power over a torpid retina, may be fitly connected with this conclusion; but on that opinion I do not build much, nor was it known to me, when I suggested the use of silver-stained glasses to the colour-blind. Their eyes are not torpid, but, so far as perception of form and outline is concerned, preternaturally sensitive to the action of light; nor do sufferers from ordinary amaurosis see better by candlelight than daylight, but the reverse.

I do not refer to these matters because the theory of the beneficial action of yellow glasses is practically important, but because I wish to impress upon the reader that it is not the mere colour of a glass or other transparent medium, that is to be regarded as the criterion of its probable utility to the colour-blind. The latter (and I only profess to assist those among them who distinguish colours better by candlelight) must select transparent media for themselves, preferring those, *whatever their colour*, which cause daylight transmitted through them, to appear as artificial light does; and it must not be forgotten that the chemical composition and molecular structure of such media, on which their relative transparency, fluorescence, diathermancy, and power to transmit or arrest actinic force depend, are probably of as much importance as their colour. Thus; of four yellow glasses stained respectively with uranium, silver, iron, and organic matter, it is probable that though their tints may be the same, they will not be of equal service to the colour-blind; for the first is highly fluorescent, the second moderately so, the third and fourth scarcely at all; and a similar remark is applicable in some degree to glasses stained with the same substance, but different in structure and composition.

Further, we must not expect to make other than an imperfect approach to the conversion of daylight into artificial light, by transmission of the former through coloured or other media, for we are as yet very ignorant of all the points of difference between them.

3. *For what professions is colour-blindness a disqualification?*

The little which art can do towards palliating colour-blindness, and the hopelessness of curing it, demonstrate the necessity of excluding from certain professions, where that is practicable, those who suffer from it. Children in whom it is discovered should be dissuaded from callings such as the house-painter's, the dyer's, and

weaver's, which have largely to do with colour; and where there is a choice, should not be strongly encouraged to follow professions like that of the analytical chemist, naturalist, botanist, geologist, or physician, which, though they admit of prosecution to a great extent by those whose sense of colour is defective, cannot be studied in some of their most important relations as sciences or arts, by such as are. Unless, therefore, the bias is strong towards the professions in question, it should be turned in another direction, though where it is powerful, as in Dalton, it will vanquish the obstacle which colour-blindness occasions.

So far as regards the fine arts, I believe that an instinctive or readily developed consciousness of an imperfect apprehension of colour, will keep the colour-blind, who have a strong love for them, from attempting to excel as colourists (though certainly this rule does not always hold), and that such persons will be found to possess an eye for form, and outline, light and shade, chiaroscuro, aerial perspective, and the other achromatic aspects of pictorial objects. This admits of ample employment and gratification in such mono-chromatic works as crayon, Sepia, and Indian ink sketching, in lithography and engraving, and most fully of all in architecture and sculpture. It is in truth much more the economical than the æsthetical chromatic arts which are forbidden to the colour-blind.

The professions, for which colour-blindness most seriously disqualifies, are those of the sailor and railway servant, who have daily to peril human life and property, on the indication which a coloured flag or a lamp seems to give. Fortunately a ship is seldom under the guidance of a single person, and in her Majesty's vessels the colour signal-men are selected from a large number, and are ascertained to have a quick eye for colour. In merchant ships, the choice must necessarily be made from a much smaller number, and the appalling yearly list of lost vessels which appears in our Wreck Returns, awakens the suspicion that more than one of these fatal disasters may have resulted from the mistaken colour of a light-house beacon or harbour-lamp, which on a strange coast, and with perhaps the accompaniments of a snow-storm or a thick fog, has been wrongly deciphered by a colour-blind pilot.

On railways the danger attending mistakes of signals is much greater than at sea, especially in this country, where trains travel at a very high speed, and succeed each other at very short intervals. Incidental reference has been made to this subject in various parts of the preceding pages, and it is much too extensive to be discussed at length here. Thus much only can be said: The most marked peculiarities of the colour-blind are shown in mistaking, (1) bright red for green; (2) dark red for brown; (3) red for black; and (4) dark or light shades of all colours for each other. The caution-signal, *green*, is thus liable to be mistaken for the danger-signal, *red* and the latter (when it appears black) not to be seen at all.

Our railway directors have, indeed, been most unfortunate in their selection of red and green for coloured signals, especially as seen through the day on flags. These colours are mistaken for each other by certain of the colour-blind, even when fresh and bright. As they darken with use, they become objects of perplexity to an additional number of such persons; and at a distance, whether new or old, they are mistaken by many who can distinguish them near. Further, they are liable, when imperfectly illuminated, as in twilight, in fogs, or snow-storms, to become altogether invisible; so that, in short, just when it is of greatest importance that they should be seen, they are most liable to be misapprehended, or not seen at all.

For this great evil there are two remedies. If the present system of signals is continued, no colour-blind person should be admitted as a railway servant. I am happy to say, that the publication of my papers has induced the Great Northern Railway Company to require that, in future, all their porters shall be tested as to their freedom from colour-blindness before they are admitted. For this wise measure the public are indebted to the exertions of Graham Hutchison, Esq., one of the directors of the company, whose attention was turned to these researches by Dr W. Mackenzie, Glasgow.

The other and better remedy, is to make the shape and movements of signals the chief index of their purpose, and to dispense with colour, except as a subordinate aid to this. Were this done, the colour-blind would not only be admissible as signal-men, but from the quick and accurate perception of form and outline, and the power of exercising this in faint light, which characterises many of them, they would often prove the best of all signallers. I must reserve, however, for another place[1] the full discussion of this important subject, and with this remark I bring this series of papers to a close.

[1] See Supplement.

SUPPLEMENT.

ON RAILWAY AND SHIP SIGNALS IN RELATION TO COLOUR-BLINDNESS.[1]

In the account of the researches on colour-blindness which I have had the honour of submitting to the Royal Scottish Society of Arts, I have repeatedly referred to the dangers which might result from the signal-men at railway stations, or on board ship, being colour-blind, and in consequence making mistakes in the exhibition or interpretation of coloured signals. I propose, in the present paper, to enter more fully into this subject, and to consider how the evil may be lessened or remedied. As it is desirable, moreover, that this communication should be complete in itself, I shall commence by *dogmatically* announcing the chief facts connected with colour-blindness, referring the reader who wishes confirmation of the following statements, or additional information on the subject, to the works mentioned below.[2]

[1] Read to the Royal Scottish Society of Arts, 8th January 1855

[2] 1. Extraordinary Facts relating to the Vision of Colours. By Mr John Dalton, Mem. Lit. and Phil. Soc., Manchester. Vol. v. 1798.

2. Wartmann, 1st Memoir on Daltonism or Colour-Blindness, translated in Taylor's Scientific Memoirs for 1846; 2d Memoir in "Deuxième Mémoire sur le Daltonisme. Genève, 1849."

3. Combe's Phrenology, article Colouring.

4. Cyclopædia of Anatomy and Physiology, article Vision.

5. W. White Cooper on Vision. 1853.

6. Dr G. Wilson, Edinburgh Monthly Med. Journal, 1853–1854; or Researches on Colour-Blindness. Sutherland and Knox, Edin.; 1855.

7. J. C. Maxwell, Transactions R.S.E. 1854–55.

I. *Of the Nature of Colour-Blindness.*

The researches of a great number of the ablest inquirers in England, Germany, France, Switzerland, and America, have, in the course of the last sixty or seventy years, brought to light the existence of a remarkable limitation of vision in reference to colours. This has been variously named, *Idiopsy* (peculiarity of vision); *Chromatopseudopsy* (false vision of colour); *Dyschromatopsy* (bad vision of colour); *Achromatopsy* (no vision of colour); *Dichromic Vision* (the vision of only two colours); and *Daltonism* (vision identical in its peculiarities with that of Dalton); but the terms of Greek origin are not significant to English readers, and are not sufficiently precise and expressive to satisfy even Greek scholars, so that I shall use none of them. Daltonism is an unsuitable and trivial name, so that in referring to the affection of sight under notice I shall restrict myself to the title Colour-Blindness, and call its subjects the Colour-Blind.

Those who are thus named differ from their more fortunate brethren in the following way: Three simple, elementary, or primary colours, properly so called, red, blue, and yellow, are visible by daylight to perfect eyes, besides white, the mutual neutralization of these colours, and black, the absence of them all.[1]

Perfect natural vision is thus a tricolor, or three-colour vision, and each of the colours of which it is cognizant may be changed by additions of white to it into *tints*, and by additions of black into *shades*, without ceasing to be visible till the paleness of the tint has made a very close approximation to white, and the darkness of the shade a very close approximation to black.

Further, the primary colours may be mixed with each other, so as to produce by the addition of red to blue, crimsons, violets, and purples; by the addition of red to yellow, scarlets and oranges; and by the addition of blue to yellow, greens; all of which secondary colours are visible both when full, and throughout a long series of tints and shades to a perfect eye; as are also the mixtures of the secondary colours with each other, giving russets (including browns) olives, and citrines.

On the other hand, the colour-blind distinguish white and black as perfectly as others do, and a very few of them have

[1] It is assumed here that the analysis of light by our sensations represents its true constitution, and that red, blue, and yellow, are its simplest ultimate sensational elements. This view is the most convenient in discussing the practical relations of colour, but is quite open to criticism as a scientific analysis of light.

no other perception of colour than that implied in the distinction between light and shade.

The great majority, however, of the colour-blind distinguish two of the primary colours, *yellow* and *blue*, but they err with the third, *red*, which they confound with *green*, with *brown*, with *grey*, with *drab*, and occasionally with other colours; and not unfrequently red is invisible to them or appears *black*. The colour-blind thus possess a *bicolor* or two-colour vision, so far as the primary colours are concerned.

Moreover, no one of the secondary colours is uniformly visible to them; orange, if tending towards yellow, appears to be yellow; if inclining to scarlet it is mistaken for green; purple is confounded with blue; and green with red and drab and brown. The tertiary colours, such as olive, russet, and citrine, are also confounded with each other, and with green, dark red, and brown.

Further, the lighter tints (among themselves) and darker shades (among themselves) of *all* colours, primary, secondary, and tertiary, are mistaken for each other, and for white in the case of the tints, and black in the case of the shades, even when not *very* pale or very dark.

The colour-blind thus perfectly distinguish only two colours, yellow and blue, and these only when deep or full; but as they are liable to mistake purple (or other mixtures of red and blue) for blue, they in reality are clearly cognizant only of yellow.

The identification, confusion, or misinterpretation of colours thus occurring, is most important, practically, in reference to red and green; but colour-blindness is most easily detected by the confusion of certain tints of purple, such as pale violet, lilac, or pink, with blue; and if lilac or pink is thus mistaken by daylight, the other mistakes characteristic of colour-blindness may be regarded as certain to occur.

By ordinary artificial light, such as lamps, candles, and coal-gas yield, red is less liable to confusion with green than by daylight; and the redder purples cease to appear only blue. Artificial light thus lessens colour-blindness, but does not abolish it, for mistakes continue to be made of the same kind, though not to the same extent as before.

The false, uncertain, defective, or negative vision of colour, which thus characterizes the colour-blind, is compatible with perfect vision in other respects, and is frequently if not generally accompanied by a very nice perception of form and outline not only in full but in faint light.

II. *Of the Number of the Colour-blind in the Community.*

Colour-blindness occurs in all ranks of the community, and

in both sexes, but more commonly in males than females. It is congenital, or at least appears as soon as it is possible to test the vision of colours in infancy, and it does not appreciably alter through life, being, so far as is yet known, totally incurable. It is also hereditary, and has been traced without material modification or abatement through five generations. It descends both by the father and mother's side, but always attaches to the sons rather than to the daughters, and if the family is considerable in number, it occurs in more than one of the sons, so that as many as six brothers have been found to be colour-blind.

It varies in degree, the extremer cases being characterized by the confusion of red (in daylight) with black, and the less extreme, only by uncertainty in the lighter and darker tints and shades of the colours characteristically confounded.

The statistics of colour-blindness are as yet imperfect, and do not include females, but there is every reason to believe that the number of males in this country who are subject in some degree to this affection of vision, is not less than 1 in 20, and that the number markedly colour-blind, *i.e.* given to mistake red for green, brown for green, purple for blue, and occasionally red for black, is not less than one in fifty. The actual number of the markedly Colour-Blind detected in an examination of 1154 males in Edinburgh was one in fifty-five, and the parties thus examined were students, soldiers, and policemen, born in various parts of the British dominions.[1]

We may thus, according to our present knowledge, regard two in every hundred of the community as *seriously* defective in their perception of colour, supposing the colour-blind to be equally divided amongst the population ; but as direct observation, as well as the prevalence in certain families of colour-blindness, demonstrates that the division is very unequal, it is impossible to calculate the extent of its prevalence in any limited area, whilst it is certain that the evils which it entails on its subjects and others, will be lessened in one district, only by increasing in another.

The following Table, repeated from page 74 of Researches on Colour-Blindness, and page 8 of Edin. Monthly Medical Journal, July 1854, will illustrate this.

[1] Edinburgh Monthly Med. Journal, July 1854, pp. 1–101 ; or Researches on Colour-Blindness, p. 72.

Distribution of the Colour-Blind among 1058 *Persons.*

Profession.	No. of Individuals.	Confound Red and Green.	Confound Brown and Green.
Professor Kelland's Students, meeting daily together for 5½ months, .	150	3	0
Edinburgh Police on duty together, .	158	1	2
Dr G. Wilson's Students, meeting daily together for 5½ months, .	20	2	0
4th Infantry, Edinburgh Castle.			
a. *Two Companies,* . . .	91	1	1
b. *Two Companies,* . . .	88	2	4
c. *Two Companies,* . . .	86	1	5
d. *Two Companies,* . . .	110	2	3
Artillery, Leith Fort.			
a. *Detachment, first day,* . .	64	2	0
b. *Detachment, second day,* . .	59	0	1
7th Hussars, Piershill.			
a. *One Troop, including 2 Officers,* .	47	2	
b. *One Troop,*	81	2	
c. *One Troop,*	49	1	2
a. Dalton and his Pupils on one occasion, ...	26	3	0
b. Dalton and other Pupils on a different occasion, ...	26	2	0
Resident Medical Officers of a Public Institution, acting together for several years, ...	3	2	0

III. *Of Visible Signals in relation to Colour-Blindness.*

In the guidance of railway trains, and of vessels at sea, signals are in constant use, which, as employed both by night and by day, are, to a great extent, significant, solely by their colour.

Those signals were introduced at a time when colour-blindness had not awakened the attention of practical observers ; and they do not contemplate its occurrence among signal-men. It is important, therefore, now to inquire what alterations the recognised prevalence of this affection of vision renders necessary in our methods of signalling.

1. *Of Railway Signals.*—The railway signals, appealing through colour to the eye, which are employed in this country, are of three kinds, namely :—*a.* Pillar or Mast-Signals,

b. Flag-Signals, *c*. Lamp-Signals. All are in use through the day; the lamps being needed in the tunnels even when the external light is brightest, and forming the only available signals during darkness.

When this system is carried out to the full, as it is in the majority of our railways, three *positive* indications, implying SAFETY, CAUTION, and DANGER, are furnished alike by the day and the night signals. On some lines, however, Caution and Danger are alone *positively* indicated,—the absence of any signal implying Safety; and on certain lines, I believe that Danger and Safety are alone *positively* indicated,—no caution-signal being shown. In what follows I shall generally suppose three positive signals to be employed at all times.

The pillar or mast-signals are of three kinds, namely, vanes, discs, and semaphores. The two first are the same in general principle, and signal only to one line, but differ in shape; the vanes being shaped like axe-heads or fish-tails,—the discs, as their name implies, being more or less circular. In the most complex signals on the first system, there is a triple vane cast in one piece of iron, and consisting of two fans in the same vertical plane, and one in a vertical plane at right angles to those two; so that the whole resembles the sign-post at a three cross-road. The double fan is painted red on both faces; the single fan is white on one face, and green on the other. The whole is made to revolve like the top of a turnstile on a vertical axis, and admits of the following movements:—When turned, so as to present the edge of the double or red fan to an approaching train, the single fan points to the left or the right, according to the direction in which the whole is turned. When the signal is to the left of the engine-driver, the WHITE side of the fan is seen, and implies "ALL RIGHT—GO ON!" When the signal is to the right, the green side of the fan is seen, and implies "CAUTION—GO SLOW!" When the single fan points *from* the observer, then the double fan conceals it, and it appears with both its right and left half RED, and the signal is "DANGER—STOP!" On the summit of the triple vane is a lamp turning with it, and showing a differently coloured glass or face along the three edges of the fans, so that at night it shows a *white* light when the single fan turns to the *left*, a *green* when it turns to the *right*, and a *red* when the two arms face the observer. In the simpler vane signals there is only a double fan, red on one face and green on the other, and showing at night lights of corresponding colours. When neither of the faces or lamps is seen, but only the edge of the vane, the signal is "Safety;" green is "Caution," and red "Danger." The triple vane, it will be

perceived, appeals to the sense of Form as well as to that of Colour; indicating *Safety*, by pointing, as it were, with one hand to the left; *Caution*, by pointing with one hand to the right, and *Danger*, by spreading out two hands.

The discs correspond to the double fan vanes, and are circular or oval plates, pierced with five or more holes, and placed on vertical spindles or axes, so that the edge of the disc or either face can be turned to any point of the compass. The one face is painted GREEN, and signifies, to a train approaching it, "*Caution—go Slow!*" The other face is painted RED, and signifies "*Danger—Stop!*" The EDGE of the disc turned towards a train implies "*All Right—Go On!*"

On some railway lines the discs are red on one side, and white on the other; and have corresponding lights, so that they signal only *Danger* and *Safety;* but in the more complex system, previously described, the arrangement is such that on the summit of the disc, and turning with it is a triple lamp, showing by night a red light above the red face of the disc, a green light above the green face, and a white light above the edge. This lamp, when *unlighted* as through the day, presents a different appearance, according as the edge or the coloured faces are turned to the observer. Thus, when the green face is towards the observer, the lens-tube of the white lamp points to one side, for example to the right, thus ⌜. When the red face is towards the observer, the white lamp points to the other side (to the left), thus ⌝. And when the edge of the disc is towards the observer, the red lamp projects on the one side, and the green on the other, so as to resemble the letter ⊤. There is thus apart from colour a difference in form in the summit of the disc-pillars, but the amount of lateral projection is very slight, in truth, so small, that it can only be seen from a short distance.

The semaphores are tall pillars or masts, which, in their simplest form, have one arm shutting up within the post, like the blade of a clasp-knife in its handle, and admitting of being opened out and fixed at an angle to the pillar. The arm is painted red on the face turned towards the engine-driver, and white on the opposite face. When shut up within the pillar, it signifies "ALL RIGHT." When raised to an angle of 45°, it denotes "CAUTION;" and when raised to an angle of 90° "DANGER." A triple lamp is also attached to the semaphore pillar, showing, as in the other arrangements, a white, green, and red light.

The flag-signals call for no special description. They consist of pieces of woollen gauze (bunting), a foot or more

square, attached to hand-staffs, and are three in number,—one white, one green, and one red.

The lamps are also three in number, provided generally with convex lenses or bull's eyes, of white, green, and red glass. All trains carry at night a white head-lamp in front of the engine, and both by night and by day a red tail-lamp attached to the last carriage. At night two or more additional red lamps are generally carried on each side of the train, and one behind on the right side of the engine.

IV. *Of the Disadvantages attending the Use of Red and Green for Railway Signal-Colours.*

Red, green, and white, have been selected alike for the vane, disc, flag, and lamp signals, as colours readily distinguished by perfect eyes, both by daylight and artificial light. It is worth while, however, to notice that red and green are open to certain objections, even when seen by those who are not colour-blind; and,

1. *Of the Perception of Red and Green by Daylight.*

1. Red as seen by day on the vanes, discs, and flags, becomes dark or imperfectly visible by faint light, such as that of the setting sun, long before blue and yellow cease to exhibit their characteristic colour.

The researches of Brewster, Dove, and Tyndall, establish this, and indeed more; for the effect of twilight is to increase positively the visibility of blue, whilst it diminishes that of red.[1]

[1] There appears to be a smaller sensibility of the human eye to red than to blue light, in all circumstances which lessen the acuteness of vision. To this I have specially referred in the Researches on Colour-Blindness, pp. 64–67; but I have not referred to another cause of the phenomenon, discussed in the text, the importance of which has been brought under my notice by my friend, Mr W. Swan.

In the Researches, I have referred to Dove's experiments with the stereoscope as establishing the visibility of blue, where red is invisible; but a stereoscope is not necessary for the demonstration of this fact. It is sufficient to contrast the appearance of the evening sky after sunset, as seen through a red and a blue glass. The former grows darker and darker as daylight departs, and rapidly becomes to all practical intents opaque: the latter, though taken of such thickness as to be darker than the red by full daylight, continues transparent so long as the faintest twilight lasts, and by contrast with the red, appears to increase in visibility and transparency as darkness comes on. Mr Swan's remarks which follow apply to the experiment as thus made.

"I see a reason for the disappearance of the red, and the continued visibility of the blue, as the darkness increases, quite independent of any difference of sensibility of the eye to these colours, which, if I recollect aright, was the explanation given of the phenomenon.

"Suppose the blue glass to be rather more opaque than the red in full day-

2. Red and Green, in virtue of their relation as complementary colours, call up each other if either is intently gazed at. The eager watcher of a signal is thus exposed to the risk of mistaking the summons to stop, for that to go slow; so that he exhibits in a very faint degree, the liability to mistake red for green, which is so marked in the colour-blind.

3. Red and green, if of corresponding tint or shade, harmonize as complementary colours to a natural eye, so that it passes readily from the one to the other without the sensation of abrupt transition. It would be better if a harsh contrast existed between the colours of the caution and danger signals, so that the eye might be startled and offended by a passage from either to the other, as the ear is by the shrill discord of the steam whistle.

If those whose vision is normal, are thus liable to mistake by day red and green for each other, those who are colour-blind are still more so. Red and green, with the exception perhaps of lilac and blue, which are too similar however to all eyes to be suitable for signals, are their greatest stumbling-blocks: to some, when fresh and bright, however near at hand: to others when new, if seen from a little distance: to all increasingly when light is imperfect.

The effect of time and exposure on the opaque signals is to darken the reds into browns, and the greens into olives, but such browns and olives are as perplexing to the markedly colour-blind as bright reds and greens, and moreover stumble the less extreme subjects of colour-blindness, by whom the purer reds and greens are tolerably well distinguished.

Those observations, it will be remembered, refer solely to the discrimination of colours by daylight. Their general ten-

light; or, to be more exact, suppose it to transmit a less percentage of the total incident light than the red does, it will then appear darker than the red. After sunset we lose the direct rays of the sun; and as twilight advances we get only rays which have suffered several reflexions in the higher regions of the atmosphere. We know from the blue colour of the sky that light reflected from the atmosphere abounds in the blue rays of the spectrum; and the more refrangible rays are precisely those which will most easily suffer reflexion, and might be expected to abound in twilight: while rays from the red end of the spectrum will be less liable to reflexion, and will probably be wanting in the twilight. The advancing twilight will therefore be made up more and more as darkness approaches, of blue or highly refrangible rays, and less and less of red, or slightly refrangible ones. The consequence will be that the red glass will transmit a constantly decreasing, and the blue glass a constantly increasing proportion of the whole incident light; and at length the red glass will become almost opaque to the light falling on it, while the blue will appear more transparent than before."

Opaque red and blue bodies act in the same way towards reflected light as transparent ones do towards transmitted light. There is thus a twofold objection to the use of red signals by day, for they are least trustworthy when light is fading, when of course they are most needed.

dency is to show, that by such illumination, red and green are the worst colours that can be selected for colour-blind handlers or interpreters of signals; and that these colours have no such superiority in the case of the normal-eyed as to make their retention specially desirable.

The question then arises, are there any colours visible to the colour-blind, and as visible to the colour-seeing as red and green, which may be substituted for these, as equally suitable for both classes of observers? The answer unfortunately is less satisfactory than could be wished.

To begin with the colour-blind. If a triple system of safety, caution, and danger colour-signals is essential to the proper working of railways, then the colour-blind must be excluded from the office of signallers. They distinguish by daylight only blue and yellow, and these solely when full in tint and well illuminated. It is true that they also see black and white, which in ordinary language are reckoned among colours. But by age, tarnish, imperfect light, snow-storms, fogs, &c., blue becomes indistinguishable from black, and white from yellow: moreover the colour-blind are liable to doubt regarding the particular tinge, or chromatic value of every colour, so that it is useless to expect them to distinguish anything more in the hours that intervene between sunrise and sunset, than one *light* colour from one *dark* colour; and it matters comparatively little what two colours are employed, provided the one approaches to white, and the other to black: in truth were all signal-men colour-blind, and two signals sufficient, white and black would be preferable to colours properly so called.

If white and black were employed, it might be possible to introduce azure or sky blue as a third signal, for it is visible to all (or nearly all) eyes, and in the morning and evening twilight shows distinctly, (for the reasons already given), where red and green cannot be distinguished. But though in favourable circumstances white, black, and blue might be distinguished from each other by the colour-blind, they could not be trusted to deal with three unlike colours under doubtful illumination, especially if taken by surprise as railway servants on occasions of special emergency must, in the majority of cases, be. I refer to the matter here chiefly because the value of Blue as a signal-colour has not been recognised in reference to those whose vision is perfect, to whom I now turn.

Seeing that the colour-blind cannot be trusted to distinguish more than two colours, and may not always be confident concerning these, it would plainly be the best plan (if colour-signals are retained) to exclude such persons altogether from the office of signal-men; but as the exhibition or

interpretation of signals may occasionally fall to the lot of parties generally engaged in other duties from which it would be difficult and perhaps unjust to exclude them, because their vision of colour is not normal; and as railway passengers have a direct interest in the signals used upon railways being such as all can distinguish and understand, it is desirable that those colours should be preferred which are best distinguished by the majority of persons.

Yellow is unquestionably the colour (properly so called) most visible to all eyes, but it is too liable under imperfect illumination to be confounded with white, to admit of being used along with it, nor could it, with any advantage, be substituted for it.

Blue comes next in visibility to Yellow, and might be advantageously substituted for green in all day signals. An azure or sky-blue can be readily and cheaply obtained. It is not confounded with red by the colour-blind. It is as visible to the normal-eyed as green under full illumination, and contrasts more sharply with red than its harmonizing complementary green does. Further, it has the peculiar advantage of remaining visible in faint daylight, and of contrasting strongly with red in such circumstances. Were it employed, the colour-blind would make fewer mistakes, and the colour-seeing would have an additional assistance in distinguishing the caution (blue), from the danger (red) signal, whilst white might continue as at present the sign of safety.

2. *Of the Perception of Red and Green by Artificial light.*

Light transmitted through coloured bodies seems more easily distinguished by the colour-blind than that reflected from coloured surfaces. This at least is the case with red and green glass through which artificial light is sent, and accordingly the lamp-signals are less liable to mistake by the colour-blind, so far as colour is concerned, than the vane and flag day-signals. But the liability to confound red with green, though less marked, still continues, even when the lamps are near the spectator; and when the distance is greater, red and green lights are not only mistaken for each other, but also for white lights.

This last mistake, according to the curious observations of Professor Tyndall, may also be made by those whose vision is normal, especially if red and green lights are alternately seen from a distance in quick succession; then apparently the combined impression of these complementary colours cannot be distinguished from that of white light.

There are other objections of more or less weight to the use of red in lamp-signals. Of these I mention three,—

1. Mr Henry Lees, the intelligent secretary of the Edinburgh, Perth, and Dundee Railway, has drawn my attention to the effect in altering the impression of distance, which the darkness of the red lamps as compared with the brightness of the white ones occasions. A red light seen from a distance seems much further off than a colourless light side by side with it, the eye assigning a less proximity to the less luminous lamp, in conformity with its experience of the different apparent brightness of lights of the same colour and luminosity placed at different distances from it. The effect of this misconception of distance must necessarily be to make danger-signals appear less near than they are, so that the red tail-lamp of a railway train standing still, will appear to a train following it, further off than it actually is, and the standing train will incur a great risk of being run into by the moving one.

There is great reason for thinking that many railway collisions have been occasioned by a miscalculation of distance originating in this way. On one of the English railways (the name of which it might be inexpedient to mention), where, as I learn from one of its engineers, trains follow each other at very short intervals through the greater part of the twenty-four hours, red tail-lamps were found so useless in preventing trains from running into each other, that they were replaced by the oldest perhaps of all night-signals, namely an open iron cage containing burning fuel, which by the dimensions of its glowing mass and the cloud of smoke and flame rising from it was conspicuous at a great distance. Where red lamps are retained, it would seem desirable to associate them with white so as to enable their distance from the spectator to be more accurately determined than it can be when they are seen alone.

2. A second objection to the red lamp was prominently indicated by a writer (who did not give his name) in the Times Newspaper two years ago, in reference to an appalling collision on one of the Irish Railways. I have mislaid the reference, and cannot give the writer's words, but he argued that an engine-driver, who must often assist his stoker in supplying coal to the furnace of the locomotive, and be exposed to the intense fiery glare of the blazing fuel, cannot be expected immediately thereafter to recognize a small red flag or red lamp unexpectedly waved in front of his engine ; and he follows this just remark by the suggestion that red port-fires of great intensity and brilliancy should be shown as danger-signals on sudden emergencies.

In truth an eye, dazzled by the red glare of a locomotive furnace, would not only be unaffected by a smaller flame of

the same colour, but in obedience to the familiar optical law of successive complementary contrast, would see or tend to see all lights green or greenish.

3. Professor James Forbes pointed out many years ago, as the result of an observation accidentally made at a railway station, that a light seen at night through steam blowing off from the escape valve of an engine-boiler appears of a deep orange-red like that of nitrous acid vapour.[1] Now it must often fall to the lot of engine-drivers to watch lamps through such an atmosphere which will convert the (white) safety signal into a danger-signal; completely alter the colour of the (green) caution-signal, and so darken the aspect of the (red) danger-signal as to render it invisible.

There are thus serious objections attending the use of red lamps on railways, yet our choice of coloured glasses is so limited that it is extremely questionable if the substitution of another colour for red would be of any service. The advantages which blue possesses for day-signals do not attend its application to lamps. Blue glass is opaque to full daylight compared with red and yellow, and still more to lamp or gas-light in which blue rays are deficient, so that it is the worst of all colours for a night signal-glass. On the other hand, the abundance of yellow rays in ordinary artificial flames points to yellow glass as one eminently visible by their transmitted rays. But in addition to its costliness it is difficult to secure a yellow which is so deep as to be distinctly distinguishable from white at a distance, and yet so pure and not inclining to orange (as the ordinary silver-stained yellow glasses generally do) as not be mistaken for red. Yellow deserves, however, a trial, either as a substitute for the red or the green signal, or as adding to our means of securing safety by association with them.

It is not to be denied that the employment of one set of signal-colours by day and another by night is a disadvantage; but an increase in the safety of travelling would more than counterbalance this; and as white would remain the safety-signal, and red could be retained as the caution-signal, but one signal would vary, which might be blue by day and yellow by night. The principle which should guide us is plainly that the danger-signal should be the most conspicuously visible of all, and were this principle unreservedly carried out, white lamps would replace red as danger-signals. But as the ordinary lights of the carriages, and at the stations, and in the neighbourhood of buildings are and must be white, we are of necessity debarred from the use of uncoloured

[1] Lond. & Edinb. Phil. Mag. 3d series, vol. xiv., p. 121.

lights as special signals, and must seek to gain our end in some other way.

V. *Of the necessity of employing the Elements of Form and Number, as well as of Colour, in Railway Signals.*

The hopelessness of providing a triple system of coloured railway-signals, which shall always be distinguishable by the colour-blind, and the imperfection of the existing system in reference even to the colour-seeing, make it desirable to connect different colours with different shapes, and to vary the number of signals, so as to heighten their dissimilarity. The acute perception of form and outline, which characterizes many of the colour-blind, enables them largely to supplement their imperfect perception of colour, and the most clear-sighted and watchful engine-drivers acknowledge that difference in shape is a great assistance in distinguishing the signals at present in use. In answer to queries not dealing with the difficulties of the colour-blind, those who are familiar with railways, have again and again told me, that when an engine is travelling at the rate of 20 or 30 miles an hour in the teeth of a cutting wind, the best eyes, even by day, and in clear weather, are often perplexed to decide at once on the colour of a signal, especially when it is suddenly and unexpectedly exhibited. It need not be added that rain, mist, fogs, high winds, snow storms, &c., must greatly increase this perplexity, or that sudden signals are those which most demand prompt recognition.

On many railways Form is used to supplement Colour, but only in certain of the day-signals, and to a smaller extent than is desirable. Thus in the semaphore, a conspicuous alteration in form is secured by exposing or concealing the moveable arm, and by fixing it at an angle of 45 or 90 degrees. In the triple vane, also, as already shown, the *white* arm points to the left of the train which it signals, the *green* arm points to the right, and the *red* signal stretches an arm in both directions. In the symmetrical double vane on the other hand, and in the corresponding disc-signals, unless where a triple lamp surmounts them, the eye has no help from form, except that on the disc, the supporting pillar on which it is fixed like a shield on a soldier's arm, is seen traversing vertically one side; but as the pillar is painted of the same colour as the disc, the difference is very inconspicuous, as it is also in the case of the lamp. In no railway, moreover, so far as I am aware, is there any distinction between the shapes of the coloured

flags, nor, unless to a small extent, is anything but colour trusted to in the lamp-signals.

So far as day-signals are concerned, I would urge strongly, that in no case should symmetrical double vanes or discs be employed. They have no advantage over unsymmetrical ones, and deprive the observer of a great assistance in interpreting the significance of a signal. Thus even in clear calm weather, and with an engine going at a moderate speed, if the disc or vane be between the engine and a bright sun, its colour (as I have ascertained from the testimony of engine-drivers), is often indistinguishable, and if it be symmetrical, it is impossible to determine whether it is signalling safety or danger. On the other hand its outline stands out with the greatest distinctness against the bright sky, and if it be shaped like a battle-axe, a broad-feathered arrow, a wind-vane, a weather-cock, a fish, or the like, the pointing of its narrow end to the right or the left of the engine-driver, will be significant of its purpose as a signal. Such unsymmetrical vanes are already in use on several railways, and should be introduced in all where the double vane or disc-system is employed.

It is less easy to apply this principle to flags, (although it forms an essential part of our naval system of signalling), as they are held so low, and generally so much within the shelter of walls and buildings, that they do not "blow out" like ship-flags or pennants, and show their form distinctly. Yet mistakes regarding flags, which at a distance from stations are often the only available day-signals in sudden emergencies, have been the cause of some of the most serious railway accidents on record, and they are, I apprehend, the least satisfactory class of railway-signals in use.

The greatest defects of flags are their smallness and dinginess. Little can be done to remedy the first evil, for they must remain portable, but much may be done to remedy the second. On all our railways, a number of the flags in use, especially those which are red and green, are so dull and discoloured by smoke, dust, and frequent handling, that they cannot be expected to catch readily the sharpest eye not specially on the look-out for them. The stout fabric (bunting) of which the flags are made, is much more durable than their colour, but the latter could at least be refreshed by occasional washing, or still better restored by re-dyeing. Something, however, more abidingly brilliant than our present flags, is demanded on railways; and if they are continued in use, they should at short intervals pass through the hands of the dyer, and some official be held responsible for their condition in reference to colour.

The white flag is the least important on the present system, and if clean, should be sufficiently conspicuous. With the coloured flags, the shape and number might be made different in each. Thus the caution-signal might be *one square* green flag; and the danger-signal, *two red* triangular ones; or in preference, a different figure might be inscribed on each flag, as a white moon-like disc on the green flag, and two white squares at opposite corners, on the red flag, so as to make the latter consist of four squares of equal size, two red and two white.

But the efficiency of all such devices is almost destroyed by the smallness of the flags, the low elevation at which they are held, and the difficulty of swinging them fully, so as to let their configuration be observed; and it is in another direction that we can most hopefully look for increasing their utility as signals.

This direction is the following:—The *motions* of a flag, apart from its colour, are employed as signals on our railways; and from the rapidity with which those motions can be executed by the direct action of a living arm, compared with the cumbrous manipulations of the more complex semaphores and vanes, a very simple set of rules is sufficient to secure safety. Thus, to take one code of signals, the flag held at arm's length in the right hand of the signal-man, and slowly waved or fluttered back and forwards, denotes "*Caution; go slow;*" elevated in front of his body, with the flag-staff held vertically, (like a soldier's sword or musket at the salute,) and kept unmoved, it signifies "*All right; go on;*" and held across the body, with the right arm raised and bent, so as to show the flag beyond the left shoulder, it denotes "*Danger; stop;*" and may be rendered more emphatic by being waved rapidly from right to left.

A single flag would thus serve for all the signals at present denoted by three flags; and without insisting on only one being retained, I would draw attention to the fact, that where the disregard of a flag has occasioned accidents on railways, it has more frequently been in consequence of the signal not being seen, than in consequence of its colour being mistaken. No prudent engine-driver who distinctly saw a flag, whatever its colour, waved violently before him, would proceed without slackening his speed.

If a single hand-signal were deemed sufficient, and it took the form of a flag, it should display two colours, the chief one being white, the other black, blue, or red, as a border or fringe, with perhaps a circle or disc of the same colour in the centre, so that the flag might be visible, whether seen against a light or a dark back-ground. Canvas painted

white, or leather, which could have a fresh white surface given to it daily if necessary, would probably be preferable to the semitransparent, less conspicuous bunting at present in use, and the entire flag should be considerably larger than those now employed. I would farther suggest, that instead of a flag, it might be advisable to employ a more conspicuous body, such as a polished reflector. A hollow ball of tin or of glass silvered inside, or two vertical vanes of tin or silvered glass, at right angles to each other, and placed at the end of a staff, would reflect light in whatever position they were held, and might catch an engine-driver's eye, where flags failed to do so.

It is of course impossible, to render visible a small signal to an engine-driver, who does not keep a look-out in front, or is engaged in assisting his stoker in managing the furnace-fire, at the time when the warning is given. To meet such a contingency, some eminently startling and conspicuous signal, such as a rocket, a blue-light, or a red port-fire, alone would suffice. Port-fires are in nominal use on one of the English railways, but apparently they are rarely employed. They deserve more attention than they have received, for the great defect attaching to all our occasional or hand-signals, is their smallness and inconspicuousness. An engine-driver knows where to expect stationary signals along a railway line, and looks out for their indications; but an unexpected signal must compel his attention, if it is to be of any service, nor can it ever be seen, or obeyed too speedily.

The night-signals as already stated, whether stationary or moveable, are significant almost solely by their difference in colour. The insufficiency of this system, however, is increasingly attracting attention, especially in reference to the meeting-points of several railway branches, where the risks of collision are unusually great.

At the Leven Junction of the Edinburgh, Perth, and Dundee Railway, Mr Bouch, C.E., has erected a very effective compound signal, which illustrates the felt necessity of not trusting to colour alone, and the mode in which it may be combined with form. It employs the combination of colour and form by day as well as by night, in the following way:—

One white Disc denotes SAFETY by day; and *one white* light, safety by night. *One green fish-tail* denotes CAUTION by day; and *one green* light, caution by night. *Two red discs* denote DANGER by day; and *two red lights*, danger by night.

This arrangement was not intended (as I learn from Mr Bouch), to meet the case of the colour-blind, but simply to assist the perception of those whose vision is normal. The

day system, however, would remove the special difficulty of the colour-blind, who have the distinctions between a disc, a fish-tail, and a double disc, to guide them in their interpretation of the signals. At night also, the double red lamp which, as the danger-signal, is the most important of all, could not be mistaken for the solitary white, or green light; but a colour-blind person might confound one of these with the other, as one not colour-blind might also in unfavourable circumstances. It would be better, therefore, to vary the numbers still further, by using for example, one white light; two green lights, and three red lights.

Such combinations of colour and form, or of colour and number, admit of endless modifications, but if our engineers are once satisfied of the necessity of employing them, it will very lightly tax their trained ingenuity to vary them, so as to meet all the requirements of railway service.

It is much more difficult to apply the principle indicated above to the hand-lamps and carriage-lamps, than to the stationary signals. So far as the carriages are concerned, the effect of recent accidents in inducing an increase in the number of red tail-lamps has been most beneficial. Three does not seem too many for the last carriage of a train, on lines where there is much traffic, especially where the train is a luggage or parliamentary one, making many halts, and liable to be run into by trains from behind. The three lamps, also, might be arranged in a triangle, or otherwise, so as to indicate, by their relative position, apart from their colour, that they were in the rear of a train, and thus be significant even to the colour-blind.*

The hand-lamps are in the same predicament as the flags, and, as shown on sudden emergencies, their visibility is of more importance than their colour; for a single light, like a single flag, may be made to indicate safety, caution, or danger, according to the direction in which it is held or waved. Were it possible, accordingly, to provide a hand-light of great brilliancy, this, no matter what its colour, would largely add to our means of preventing accidents on railways. There is no prospect of this desideratum being realized with lamps fed with oil or similar combustibles, but it is quite within our reach by those pyrotechnic mixtures which, under the names of blue lights, and red and green fire, are employed as night-signals by our army and navy. The least conspicuous of these

* On some of the English railways the entire back, and part even of the sides of the last carriage of the train, are painted bright red, so as to expose a very large and conspicuous coloured surface. Were this lighted at night by colourless lamps, provided with reflecting shades, it would probably be visible at a greater distance than red lamps would be; but the exigencies of railway service do not always allow the same carriage to be the last in a train.

is the green fire, the most brilliant the blue light, and the most startling the red fire.[1] They are supplied by firework-makers in cartridges, and can be lighted at a moment's notice. The blue light is the cheapest, and its peculiar lurid flame is not liable to be mistaken for that of an ordinary conflagration, which the splendid crimson blaze of the strontia fire might be. All of them illuminate a wide area; in truth, the only objection I can conceive to their use is, that they might alarm too great an extent of country; but this is an error in the right direction; and it may be safely asserted that more than one appalling night accident would have been prevented had the guards of a train, brought to an unexpected stand-still, had the means of suddenly showing a blazing light. The reluctance of guards and stokers to leave their trains and run back some distance with red lamps is brought out at every criminal trial following a night accident on a railway.

The difficulty, also, often experienced in conveying to the nearest stations a knowledge of the fact that there exists an obstruction on the line, is scarcely less notorious. The port-fires, referred to, however, would be visible at a great distance, even though kindled close to the train brought to a stand-still; and they would often suffice to warn the adjoining stations that an accident had occurred in their neighbourhood.

Red and green lamps are employed as signals at sea, as well as on land; and as peculiar dangers attend their employment on shipboard, it will be convenient to consider that subject here, before proceeding to discuss the best modes of testing the colour-vision of signal-men.

VI. *Of the Danger attending the System of Red and Green Lights, at present in use on board Steam Vessels.*

In the Admiralty Notice respecting lights to be carried by sea-going vessels, to prevent collision, which came into force in August 1852, and still regulates their system of night signals, the following rules are required to be strictly observed by all British steam-vessels. Between sunset and sunrise, when under steam, they are to show a bright *white* light on the foremast head; a *green* light on the starboard side; a *red* light on the port side.

The side lights are, moreover, to be fitted with screens, on the inboard side, of at least three feet long, to prevent the lights from being seen across the bow.

[1] Receipts for these mixtures will be found in works on Chemistry. The green fire is a mixture of sulphur and other combustibles with nitrate of baryta; the red fire, a similar mixture with nitrate of strontia; and the blue light a mixture of sulphuret of antimony, and sulphur with nitrate of potash.

The object of the screens, which are regarded by their devisers as the most novel and important part of their plan, is "to prevent both coloured lights being seen at the same moment from any direction but that of right-a-head;" and the expectation, as stated in the official notice, is, that the effect of the arrangement proposed will be such, "that in any situation in which two vessels may approach each other in the dark, the coloured lights will instantly indicate to both the relative course of each; that is, each will know whether the other is approaching directly or crossing the bows, either to starboard or to port. This intimation is all that is required to enable vessels to pass each other in the darkest night with almost equal safety as in broad day, and for the want of which so many lamentable accidents have occurred."

The expectation expressed in the paragraph I have quoted will be realized where two vessels approach each other directly. Let both be steamers, then the steersman of each will, whether colour-blind or not, see a triangle of lights approaching; and, if not colour-blind, will also perceive, as shown in the diagram (Fig. 1), a green light on the starboard side, and a red on the port side of the advancing vessel.

Fig. 1.



But when vessels are crossing each other's bows, the foremast *white* light goes for nothing, and the colour of the steamer's *one* side-light seen is, to the vessel seeing it, the index whether the steamer is crossing to starboard or port, *i.e.*, in landsman's phrase, to the right hand or left hand of the steersman who perceives only the green, or only the red light. This is shown in Figs. 2 and 3, where one vessel is supposed

Fig. 2.



to cross the path of another at right angles; both are repre-

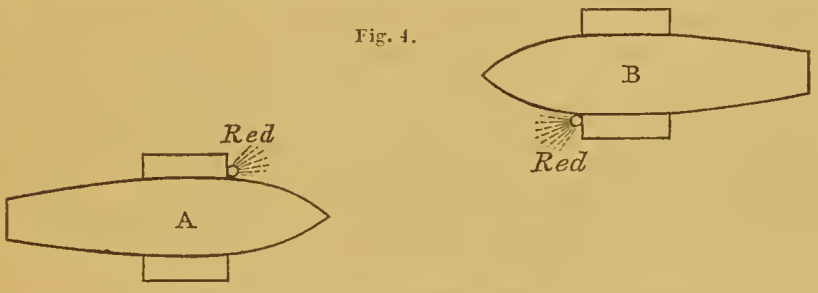
sented as paddle steamers. The steersman of B in both cases should see all the lights of A, and be warned of a steamer's direct approach, whether he distinguished the colour of the side-lights or not.

Fig. 3.



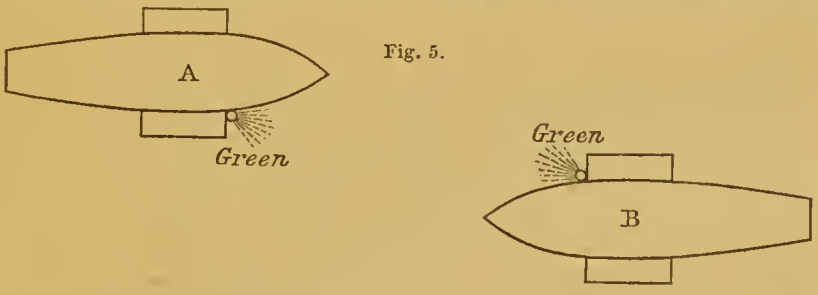
But the steersman of A has only the colour of one of B's side-lights, to tell him, whether, as in Fig. 2, B is crossing to starboard (his right hand); or as in Fig. 3, to port (his left hand); and if he be the only look-out, and *is colour-blind, he will be uncertain whether to port or starboard his helm.*

Fig. 4.



Again, in Fig. 4, A and B will see each other's red light only, the screens preventing the green lights from being seen; and both vessels passing to port. In Fig. 5, on the other hand, a

Fig. 5.



green light only will be visible to each, the screens preventing the red lights from being seen; and both vessels passing to starboard.

Now if the pilots of A or B, one or both, are colour-blind, of what service will the colour of the one side-light be? I reply,

without hesitation, of less than no service. The red lamp may be mistaken for green, or the reverse, and a collision determined by the mistake. In no case will a colour-blind pilot be absolutely certain as to the colour of the side-light, and the vacillation which shall attend his attempt to come to a conclusion may not be exchanged for action till it be too late to prevent a collision. Further, as a pilot, conscious of his colour-blindness, will guide himself mainly by the direction in which he sees a light crossing his bows, he is exposed to the disadvantage of watching a green or a red light, which is not visible so far off as a white one, and is also liable from its comparative obscurity to appear further off than it actually is. Moreover, from all my examinations of the colour-blind, I am satisfied that however conscious they may be of their peculiarity of vision, they will always, if given to understand that an object is coloured, try to decide what its colour is, and yet, in the majority of cases, hesitate regarding the justice of their conclusion. The distraction of mind thus occasioned is fatal to that promptitude of action which must often be the first duty of a pilot.

The Admiralty Notice, from which I have quoted, contains in a note the statement, that "the system of night-lights laid down in the above regulations has been adopted in Her Majesty's Service, and by the Governments of the principal Foreign Maritime Nations." This announcement must be read with grave apprehension by all who are familiar with the statistics of colour-blindness; for colour *alone* is relied upon to instruct a pilot how to steer clear of a steamer in a dark night; and the mistake of red for green, or the reverse, would be still more disastrous at sea than on shore, for the object of a railway danger (red) signal would often be sufficiently secured, though it were interpreted only as a caution (green) signal; and the purpose of a caution signal would be more than secured if it were understood as a warning of danger. But at sea, to mistake either of these lights for the other, would equally and inevitably lead to a vessel being steered so as to determine a collision.

In Her Majesty's Naval Service, and in our Commercial Marine, the safety at least of the larger vessels is in charge during night of a whole watch of men; but even in those ships the steering of the vessel is not unfrequently under the guidance of a single pilot, whose word is law, and who may be colour-blind, but unconscious of the fact, or afraid to confess it. And in smaller vessels, especially those not in Her Majesty's Service, it is notorious, that whatever the theory of night-watching may be, the fact is that the safety of a ship is often to all practical intents in the hands of the steersman

alone, whose power to distinguish red from green may be null. The Admiralty system of night-lights, accordingly, is trustworthy, only provided the freedom of pilots and look-outs from colour-blindness is guaranteed; and at present no means are taken to determine this. It would be so difficult, however, to render certain the exclusion from the office of pilot or look-out of such members of a large crew as were colour-blind, and so inexpedient to refuse employment on board ship to those who were, but at the same time possessed all the other qualifications of good sailors, that I cannot but urge the desirableness of changing the system of night-lights at sea for one which the colour-blind cannot mistake. This need not prevent coloured lamps from being employed, although it is desirable that on board war-ships and others provided with surgeons, the medical officers should report those of the crew who are colour-blind, so as to prevent their employment (whether by day or night), as special signal-men. By varying the number, or relative position, or both of the port and starboard lights in the way already indicated in the case of railway lamps, or otherwise, it seems quite possible, without depriving those who can distinguish it, of the assistance afforded by difference in colour, to enable the colour-blind to act safely as night-pilots. The mode in which this may best be effected, I leave to the decision of seamen who are satisfied that the prevalence of colour-blindness necessitates a change in the Admiralty system of lights. It is sufficient for me to urge that that system is fraught with unsuspected danger to all who trust in it.

VII. *Of the best modes of detecting Colour-Blindness.*

It admits of question, whether the demands of public safety would be best met by excluding colour from railway and ship signals, or by excluding the colour-blind from the office of signal-men.

The answer, however, must be that the alternative is not in our choice. It must necessarily happen, both at land and sea, that those not specially set apart as the exhibitors or interpreters of signals, have at times to act as such, and the most sudden emergencies are exactly the occasions on which the least qualified and least experienced are most liable to a summons of this kind. We cannot, therefore, be too careful to make our signals significant by other characters besides that of colour.

On the other hand, the colour-blind are a minority in the community; and those peculiarly destined to deal with signals should be selected solely from the majority whose vision is normal. Colour is of great service to them in dis-

tinguishing visible objects ; and it should, therefore, assuredly be retained in signals. I have the authority of railway engineers for stating, that frequently when a signal is seen by reflected light,—for example, by the sun's rays shining from behind an engine-driver upon a signal which his train is approaching,—its shape gives no assistance in discerning it if it is projected against a background of its own colour ; as the green signal may be against trees in leaf, or hills in pasture, and the red when tarnished or as seen by twilight, against newly ploughed ground. That this difficulty is generally recognised, I infer from the fact, that on several railways the red side of the signal-vanes is painted with a white border, and on others the centre of the green side, where there is an open star, has its rays painted white. On the North British Railway, in the immediate neighbourhood of Edinburgh, green is dispensed with, and the vanes are red, with a white border on the one side, and red alone on the other.

As the most normal eye thus needs every help in distinguishing signals by their colour, when their form is uncertain, it is desirable that the simplest means of detecting colour-blindness, and of estimating its extent, should be known to those concerned in the appointment of signal-men.

The most testing colours by daylight are red as compared with light-green ; brown as compared with olive and dark-green, and lilac, as compared with blue.

By artificial light, in addition to the colours named above as exhibited by flags and painted opaque surfaces, coloured lamps will, of course, be employed ; and red, green, and purple glass, viewed by transmitted light, are also useful by day. In all cases the vision of colour should be tested at various distances from the coloured object; and none should be passed who err in the majority of trials regarding a signal seen from the furthest point at which it must be swiftly interpreted to secure safety. For it must not be forgotten that certain of the colour-blind distinguish pretty fairly colours (such as red and green) near at hand, which they confound at some distance. And for a similar reason their vision should be tried under various degrees of illumination, and in particular the visibility of the testing colours by twilight should be specially ascertained.

Candidates for appointments where good eye-sight is required, are not likely to exaggerate their defects of vision. Whenever, therefore, any hesitation in distinguishing colours is manifested, it should be further tried by giving the party under examination, parcels of differently coloured cloth, paper, glass and the like, and requesting him to assort them according to their colours. Reds, greens, browns, and lilacs, should form an essential part of these parcels, but not to the ex-

clusion of other tints and shades. No person markedly colour-blind, will, I am persuaded, escape detection if tried in this way, and the kind and number of mistakes which he commits will measure the extent of his colour-blindness.

The mode of examination thus explained is within the reach of railway-superintendents and ship-masters, and will serve every practical end. But where railway-servants, sailors, soldiers, or others, undergo preliminary examination by a surgeon, a more minute examination might be made, and in another way. Mr James Clerk Maxwell, of Trinity College, Cambridge, a mathematician and natural philosopher of the highest promise, has devised a most simple and effectual means of discovering the nature and extent of colour-blindness. It is described in the communication from Mr Maxwell which is appended to this (page 153), and at greater length in a paper which appears in the Transactions of the Royal Society of Edinburgh, Vol. xxi., Part ii., p. 275. To these the reader is specially referred; but it will not be out of place to state here that Mr Maxwell employs a disc of pasteboard, or metal, provided with a spindle, so as to admit of it being spun as a top or teetotum. The spindle is in two pieces, and can be unscrewed so as to allow discs of coloured paper, perforated in the centre to receive the spindle, and with a slit corresponding to a radius of the disc, to be placed on the upper surface of the top, the rim or circumference of which is divided into 100 equal parts. The paper discs admit of being placed above each other, and any portion of one disc may be made to appear above another, by passing one edge of its slit through the slit in the other.

Thus, let a disc of red and a disc of white paper be placed together on the top, the white being the lower of the two; we may then, if we choose, cover the white entirely by the red, so that the latter only shall appear; or at will, bring the white through the slit in the red so as to let one-tenth, one-twentieth, one-twelfth, or the like quantity of the surface of the white cover that amount of the surface of the red. When the top is made to spin, one of the tints (dilutions with white) of red will be obtained, and the quantity of red and white in it may be measured by the graduation on the circumference of the circle.

In the same way a circle of red and a circle of black will give the shades (deepenings with black) of red; and the delicacy of an eye in distinguishing the nicer gradations of colour, may be quantitatively determined.

Again, small discs (half the diameter of the larger ones) of green, and of white or black paper, may be placed on the colour-top above the larger red and white or black discs, so

that when the top is spinning, a green circle, surrounded by a red ring will be visible to a normal eye, and these may be compared throughout their tints and shades.

This little instrument, (which however any one can construct for himself), may be had with a series of selected coloured papers, from Mr James Bryson, optician, Edinburgh. I can testify from experience to the rapidity with which it enables colour-blindness to be detected, and Mr Maxwell's papers will demonstrate the number and value of the results which it may be made to yield in the examination of normal and abnormal eyes.

I have lastly to notice, that there is a singular expression in the eye of certain of the colour-blind, which may assist in their detection. It is difficult to describe it, and it is wanting in well-marked cases. But various of the colour-blind, whose cases I have described, have presented a peculiarity of look, which others have recognised on their attention being drawn to it. In some it amounted to a startled expression, as if they were alarmed; in others to an eager, aimless glance, as if seeking to perceive something but unable to find it; and in certain others to an almost vacant stare, as if their eyes were fixed upon objects beyond the limit of vision. The expression referred to, which is not at all times equally pronounced, never altogether leaves the eyes which it seems to characterize.

Whether its occurrence in those colour-blind persons whom I have examined is but a coincidence, (which it may be), or the unconscious betrayal of a defective sense, I do not attempt to decide; but I mention the matter here that future observers may keep it in view.

ON THE

THEORY OF COLOURS IN RELATION TO COLOUR-BLINDNESS.

By JAMES CLERK MAXWELL, B.A.,
TRINITY COLLEGE, CAMBRIDGE.

IN A LETTER TO DR G. WILSON.

Dear Sir,—As you seemed to think that the results which I have obtained in the theory of colours might be of service to you, I have endeavoured to arrange them for you in a more convenient form than that in which I first obtained them. I must premise, that the first distinct statement of the theory of colour which I adopt, is to be found in *Young's Lectures on Natural Philosophy* (p. 345, Kelland's Edition); and the most philosophical inquiry into it which I have seen is that of Helmholtz, which may be found in the Annals of Philosophy for 1852.

It is well known that a ray of light, from any source, may be divided by means of a prism into a number of rays of different refrangibility, forming a series called a spectrum. The intensity of the light is different at different points of this spectrum; and the law of intensity for different refrangibilities differs according to the nature of the incident light. In Sir John F. W. Herschel's *Treatise on Light*, diagrams will be found, each of which represents completely, by means of a curve, the law of the intensity and refrangibility of a beam of solar light after passing through various coloured media.

I have mentioned this mode of defining and registering a beam of light, because it is the perfect expression of what a beam of light is in itself, considered with respect to all its properties as ascertained by the most refined instruments. When a beam of light falls on the human eye, certain sensations are produced, from which the possessor of

that organ judges of the colour and intensity of the light. Now, though every one experiences these sensations, and though they are the foundation of all the phenomena of sight, yet, on account of their absolute simplicity, they are incapable of analysis, and can never become in themselves objects of thought. If we attempt to discover them, we must do so by artificial means; and our reasonings on them must be guided by some theory.

The most general form in which the existing theory can be stated is this,—

There are certain sensations, finite in number, but infinitely variable in degree, which may be excited by the different kinds of light. The compound sensation resulting from all these is the object of consciousness in a simple act of vision.

It is easy to see that the *number* of these sensations corresponds to what may be called in mathematical language the number of independent variables, of which sensible colour is a function.

This will be readily understood by attending to the following cases:—

1. When objects are illuminated by homogeneous yellow light, the only thing which can be distinguished by the eye is difference of intensity or brightness.

If we take a horizontal line, and colour it black at one end, with increasing degrees of intensity of yellow light towards the other, then every visible object will have a brightness corresponding to some point in this line.

In this case there is nothing to prove the existence of more than one sensation in vision.

In those photographic pictures in which there is only one tint of which the different intensities correspond to the different degrees of illumination of the object, we have another illustration of an optical effect depending on one variable only.

2. Now, suppose that different kinds of light are emanating from different sources, but that each of these sources gives out perfectly homogeneous light, then there will be two things on which the nature of each ray will depend:—(1.) its intensity or brightness; (2.) its hue, which may be estimated by its position in the spectrum, and measured by its wave length.

If we take a rectangular plane, and illuminate it with the different kinds of homogeneous light, the intensity at any point being proportional to its horizontal distance along the plane, and its wave length being proportional to its height above the foot of the plane, then the plane will display every possible variety of homogeneous light, and will furnish an instance of an optical effect depending on two variables.

3. Now, let us take the case of nature. We find that colours differ not only in intensity and hue, but also in tint; that is, they are more or less pure. We might arrange the varieties of each colour along a line, which should begin with the homogeneous colour as seen in the spectrum, and pass through all gradations of tint, so as to become continually purer, and terminate in white.

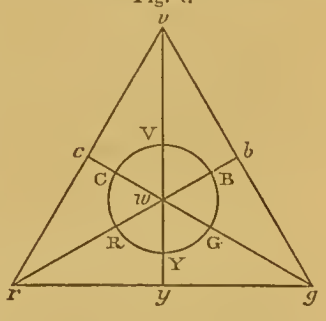
We have, therefore, three elements in our sensation of colour, each of which may vary independently. For distinctness sake I have spoken of intensity, hue, and tint; but if any other three independent qualities had been chosen, the one set might have been expressed in terms of the other, and the results identified.

The theory which I adopt assumes the existence of three elementary sensations, by the combination of which all the actual sensations of colour are produced. It will be shown that it is not necessary to specify any given colours as typical of these sensations. Young has called them red, green, and violet; but any other three colours might have been chosen, provided that white resulted from their combination in proper proportions.

Before going farther I would observe, that the important part of the theory is not that three elements enter into our sensation of colour, but that there are only three. Optically, there are as many elements in the composition of a ray of light as there are different kinds of light in its spectrum; and, therefore, strictly speaking, its nature depends on an infinite number of independent variables.

I now go on to the geometrical form into which the theory may be thrown. Let it be granted that the three pure sensations correspond to the colours red, green, and violet, and that we can estimate the intensity of each of these sensations numerically.

Fig. 1.



Let v r g be the angular points of a triangle, and conceive the three sensations as having their positions at these points. If we find the numerical measure of the red, green, and violet parts of the sensation of a given colour, and then place weights proportional to these parts at r g and v, and find the centre of gravity of the three weights by the ordinary process, that point will be the position of the given colour, and the numerical measure of its intensity will be the sum of the three primitive sensations.

In this way, every possible colour may have its position and intensity ascertained; and it is easy to see that when two compound colours are combined, their centre of gravity is the position of the new colour.

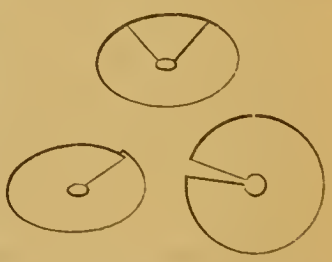
The idea of this geometrical method of investigating colours is to be found in Newton's *Opticks* (Book I., Part 2, Prop. 6.), but I am not aware that it has been ever employed in practice, except in the reduction of the experiments which I have just made. The accuracy of the method depends entirely on the truth of the theory of three sensations, and therefore its success is a testimony in favour of that theory.

Every possible colour must be included within the triangle *r g v*. White will be found at some point, *w*, within the triangle. If lines be drawn through *w* to any point, the colour at that point will vary in hue according to the angular position of the line drawn to *w*, and the purity of the tint will depend on the length of that line.

Though the homogeneous rays of the prismatic spectrum are absolutely pure in themselves, yet they do not give rise to the "pure sensations" of which we are speaking. Every ray of the spectrum gives rise to all three sensations, though in different proportions; hence the position of the colours of the spectrum is not at the boundary of the triangle, but in some curve C R Y G B V considerably within the triangle. The nature of this curve is not yet determined, but may form the subject of a future investigation.

All natural colours must be within this curve, and all ordinary pigments do in fact lie very much within it. The experiments on the colours of the spectrum which I have made are not brought to the same degree of accuracy as those on coloured papers. I therefore proceed at once to describe the mode of making those experiments which I have found most simple and convenient.

Fig. 2.



The coloured paper is cut into the form of discs, each with a small hole in the centre, and divided along a radius, so as to admit of several of them being placed on the same axis, so that part of each is exposed. By slipping one disc over another, we can expose any given portion of each colour. These discs are placed on a little top or tectotum, consisting of a flat disc of tin-plate and a vertical axis of ivory. This axis passes through the centre of the discs, and the quantity of each colour exposed is measured by a graduation on the rim of the disc, which is divided into 100 parts.

By spinning the top, each colour is presented to the eye for a time proportional to the angle of the sector exposed, and I have found by independent experiments, that the colour produced by fast spinning is identical with that produced by causing the light of the different colours to fall on the retina at once.

By properly arranging the discs, any given colour may be imitated and afterwards registered by the graduation on the rim of the top. The principal use of the top is to obtain colour-equations. These are got by producing, by two different combinations of colours, the same mixed tint. For this purpose there is another set of discs, half the diameter of the others, which lie above them, and by which the second combination of colours is formed.

The two combinations being close together, may be accurately compared, and when they are made sensibly identical, the proportions of the different colours in each is registered, and the results equated.

These equations in the case of ordinary vision, are always between four colours, not including black.

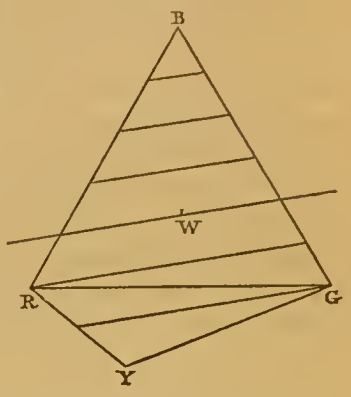
From them, by a very simple rule, the different colours and compounds have their places assigned on the triangle of colours. The rule for finding the position is this :—Assume any three points as the positions of your three standard colours, whatever they are ; then form an equation between the three standard colours, the given colour and black, by arranging these colours on the inner and outer circles so as to produce an identity when spun. Bring the given colour to the left-hand side of the equation, and the three standard colours to the right hand, leaving out black, then the position of the given colour is the centre of gravity of three masses, whose weights are as the number of degrees of each of the standard colours, taken positive or negative, as the case may be.

In this way the triangle of colours may be constructed by scale and compass from experiments on ordinary vision. I now proceed to state the results of experiments on Colour-Blind vision.

If we find two combinations of colours which appear identical to a Colour-Blind person, and mark their positions on the triangle of colours, then the straight line passing through these points will pass through all points corresponding to other colours, which, to such a person, appear identical with the first two.

We may in the same way find other lines passing through the series of colours which appear alike to the Colour-Blind. All these lines either pass through one point or are parallel, according to the standard colours which we have assumed, and the other arbitrary assumptions we may have made. Knowing this law of Colour-Blind vision, we may predict any number of equations which will be true for eyes having this defect.

Fig. 3.



The mathematical expression of the difference between Colour-Blind and ordinary vision is, that colour to the former is a function of two independent variables, but to an ordinary eye, of three; and that the relation of the two kinds of vision is not arbitrary, but indicates the absence of a determinate sensation, depending perhaps upon some undiscovered structure or organic arrangement, which forms one-third of the apparatus by which we receive sensations of colour.

Suppose the absent structure to be that which is brought most into play when red light falls on our eyes, then to the Colour-Blind red light will be visible only so far as it affects the other two sensations, say of blue and green. It will, therefore, appear to them much less bright than to us, and will excite a sensation not distinguishable from that of a bluish-green light.

I cannot at present recover the results of all my experiments; but I recollect that the neutral colours for a Colour-Blind person may be produced by combining 6 degrees of ultramarine with 94 of vermilion, or 60 of emerald-green with 40 of ultramarine. The first of these, I suppose to represent to our eyes the kind of red which belongs to the red sensation. It excites the other two sensations, and is, therefore, visible to the Colour-Blind, but it appears very dark to them and of no definite colour. I therefore suspect that one of the three sensations in perfect vision will be found to correspond to a red of the same hue, but of much greater purity of tint. Of the nature of the other two, I can say nothing definite, except that one must correspond to a blue, and the other to a green, verging to yellow.

I hope what I have written may help you in any way in your experiments. I have put down many things simply to indicate a way of thinking about colours which belongs to this theory of a triple sensation. We are indebted to Newton for the original design; to Young for the suggestion of

the means of working it out; to Prof. Forbes[1] for a scientific history of its application to practice; to Helmholtz for a rigorous examination of the facts on which it rests; and to Prof. Grassmann (in the Phil. Mag. for 1852), for an admirable theoretical exposition of the subject. The colours given in Hay's "*Nomenclature of Colours*" are illustrations of a similar theory applied to mixtures of pigments, but the results are often different from those in which the colours are combined by the eye alone. I hope soon to have results with pigments compared with those given by the prismatic spectrum, and then, perhaps, some more definite results may be obtained.

Yours truly,

J. C. MAXWELL.

EDINBURGH, 4*th Jan.* 1855.

[1] Phil. Mag., 1848.

APPENDIX.

NOTE A.

ON THE TERMS DALTONISM AND DALTONIAN.

In connection with page 6.

Professor Wartmann, in his "Deuxième Mémoire sur le Daltonisme, ou la Dyschromatopsie; Genève, 1849," pp. 1–4, refers to the "reclamations" raised in this country, by myself and others, against the use of the words Daltonism and Daltonian, in his first memoir; and after showing that he only followed Prevost, who was justified by Dalton's own account of his case, in using those terms, vindicates their continued employment, by a demonstration of their convenience, and their general adoption abroad.

Wartmann was assuredly blameless in his use of the questionable words, as I have fully acknowledged in the text of this work (p. 6), and, along with Prevost, may justly appeal to Dalton, as *tacitly* warranting their employment. This no one who has read Dalton's own memoir will question, and I have dwelt upon the point in the Appendix to Dr Henry's Life of Dalton, p. 240. (*Printed for the Cavendish Society*, 1854.)

At the same time, however difficult it may be to supply terms as convenient as "Daltonism," and still more "Daltonian," are, I think the accomplished continental philosophers who vindicate their employment will not be indifferent to the following argument against their use.

It has never been the practice of the civilized nations of Europe, in their graver writings, to connect the name of an individual with a secondary or trivial point in his history, opinions, or character; but, on the other hand, when they have embodied a surname in a noun or adjective, it has had reference to the most prominent moral or intellectual features which have characterised the individual, and rendered him famous or infamous.

Such terms as Simony, Machiavellianism, Socratic, Platonic, Aristotelian, Cartesian, Copernican, Baconian, Newtonian, Lutheran, Calvinistic, Galvanic, Voltaic, and many more, connect those from whose names they are taken with the most prominent acts or thoughts which have made them memorable for good or evil.

There are doubtless exceptions, as in the word "Cæsarian," in its medical application to a special abdominal section, but the exceptional rarity and peculiarity of such cases establish the rule which they transgress. Now, applying this rule, I ask, "Is Colour-blindness the feature in Dalton's individuality for which his name is now, and is long likely to be preserved in remembrance?"

It may have been the most memorable thing about him when he published the account of his peculiarity of vision in 1798. But now, his discoveries in Physics, and above all, his speculations on Atomics, are the things that make him famous, and Daltonism *should* signify the Doctrine of Indivisible Chemical Atoms; and a Daltonian, a believer in such. I submit, therefore, that it is as unbecoming to commemorate by Daltonism and Daltonian the defect in the eyes of Dalton, as it would be to signify by the word Socratic the possession of an ill-shaped nose like that of Socrates.

NOTE B.

ON THE PARALYSING INFLUENCE OF INTENSE LIGHT ON THE RETINA.

In connection with page 42.

As stated in the text, "when red, blue, or yellow is diluted with white, a point is ultimately reached with every eye at which the excess of uncoloured light accompanying the colour renders the retina insensitive to the impression of the latter." I had recently an unexpected opportunity of observing the paralysing influence of intense light on the retina, which, though not bearing more on the phenomena of colour-blind than of normal vision, seems of sufficient interest to deserve record.

On the evening of the 6th of June 1855, a severe thunderstorm, accompanied by a very splendid show of lightning, visited Edinburgh. With no special object, other than to observe the splendour of the sight, I shut myself, about 11 P.M., in a small room, commanding a full view of the southern sky. Between the intervals of the lightning, the illumination was very faint, but a road-lamp, about a hundred feet distant, shining obliquely through the window, cast the shadow of its bars distinctly on a side wall.

When the great flashes came, they lasted for an appreciable time, were rose-coloured or pale-purple, and very brilliant, and I was startled by observing, that after their occurrence I became for a sensible period totally blind. The sky, the window, and the reflection on the wall, utterly vanished. I felt as if some solid, opaque, black mass touched my face, a sensation quite different from that experienced in ordinary darkness; and from this I emerged in a moment, to perceive the window and its frame.

I was taken by surprise the first time this blindness occurred, but as the discharges of lightning continued till midnight, I repeated the observation with the same result more than a dozen times, placing my finger on the upper eye-lid so as to make certain that I did not close it in consequence of the flash. I observed no complementary white bars on a black window, or any yellow spectrum answering to the purple flashes; the retina was utterly paralysed, and presented no luminous image at all.

The high luminous intensity of electric flashes is generally overlooked, owing to their colour, although attention has been directed to their brightness by more than one writer. Sunlight may be as bright or brighter, but we cannot voluntarily subject our eyes to its influence, as we can or rather must, to the glare of lightning, whose duration is so fleeting, that we cannot escape from its brightness.

NOTE C.

ON THE RELATIVE VISIBILITY OF RED AND BLUE BY TWILIGHT.

In connection with pages 64, 67.

In a note to page 134 of the Supplement, I have referred to the twofold explanation which may be given of the diminished visibility of red, and increased visibility of blue, by twilight. In the text and Supplementary Note the phenomenon is illustrated almost entirely by reference to the stereoscope and to sheets of coloured glass, but it may be observed quite as well with flowers or tinted papers. Nothing, indeed, shows it better than paper coloured by ultramarine on which letters are printed. In full daylight the blue dazzles the eye, and the black letters, if small, are read with an effort. At ten or eleven P.M. in the middle of June, the ultramarine seemed as pale as blue writing paper, and the printed letters stood out from it in most striking contrast. By the same light, paper coloured with carmine or vermilion appeared nearly black, and in bouquets of flowers those which, from their redness, were most conspicuous by daylight were darkest. Thus, a brilliant scarlet anemone, a red japonica (*Pyrus* or *Cydonia japonica*) and a crimson rhododendron were recognized only by their form, whilst a blue gentian (*Gentianella*), which was the darkest flower by day, lightened into a pale grey under advanced twilight. When a series of flowers, arranged by another person in a group, was given me by midsummer twilight, I found that I missed altogether some of the red flowers, and inferred the colour of others of the same tint only from their shape. Yellow flowers had a strange lurid colour, and blue petals seemed of a watery grey or pale neutral tint. It is startling to transfer suddenly such a pallid and dusky nosegay to artificial light. Bright reds and yellows start into view where there was least promise of colour, and pale greys deepen into dark blues.

How far those results depend on the diminished number of red rays in twilight, how far on the smaller sensibility of the retina to weak red than to weak blue light, I cannot as yet determine. It is even a question whether there is any difference in the visibility of red and blue light when they are furnished to the retina of equally low intensity and in equal quantity; but a satisfactory *experimentum crucis* on this point has not been made.

It has seemed to me that dark purple flowers, in which, close at hand, red was distinctly visible, appeared at a short distance, and by full daylight, only blue, or at least much bluer, but here there was from the first much more blue in them than red, nor does the observation admit of great precision.

NOTE D.

ON THE STATISTICS OF COLOUR-BLINDNESS AMONG FEMALES.

In connection with page 75.

Since the text was written I have been informed of a few more cases of colour-blindness occurring among educated women in this country, but I

have not been so fortunate as to encounter any of these cases, so as to describe its peculiarities. As the ladies in question, however, betrayed themselves, when purchasing silk, by the characteristic mistakes of the colour-blind in reference to red, and were known not to be able to distinguish poppies among unripe corn, there can be no question concerning the quality of their vision. The general tendency, however, of my later inquiries, as of my earlier ones, is to show that colour-blindness is very much rarer among women than men. From Wartmann's *Deuxième Mémoire*, p. 19, which was not in my hands when the text of the statistics was written, I learn the particulars of an interesting case illustrating this. Dr Pliny Earle, of the United States, numbers among seventy-one relatives, thirty-two of whom are males and twenty-nine females, twenty cases of colour-blindness, but of these eighteen occur in the males, and only two in the females.* Wartmann also quotes from Dr F. Cunier a remarkable example of colour-blindness attaching to the females rather than to the males in a family line, and this through five generations.

Madame O., residing near Mons, cannot distinguish deep blue from cherry-red. Her mother and her two sisters are similarly circumstanced; her brother's vision is normal. Madame O. has had six children, one son, who is not colour-blind, and five daughters, whose vision is like her own. The oldest of these daughters has four children, two of whom are girls, and have inherited the vision of their mother. The second has a boy and a girl,—the latter is colour-blind. The third has one child, a boy, whose vision is normal. The fourth is not married. The fifth has left a boy, who is short-sighted, but not defective in his perception of colours. So that in this line colour-blindness has descended solely through the mothers, and solely to the daughters. The original account of this singular case is contained in *Annales d'Oculistique*, t. i. p. 417. (Quoted in Wartmann's *2de Mémoire*, p. 19.)

NOTE E.

ON THE RELATION OF THE YELLOW SPOT OF THE RETINA TO COLOUR-VISION.

In connection with page 83.

Mr James Clerk Maxwell has communicated to me a very interesting observation on the relative visibility of yellow and blue light when received on the yellow spot of the retina, which, in illustration and extension of the subjects discussed at pages 83-87 of the text, I give here in his own words, from a letter dated July 27, 1855.

"Last year I was observing the spectrum formed by a long slit, using a single prism and the naked eye. I then first observed that a peculiar dark appearance (which I supposed to belong to the blue near the line F) extended only to that part of the spectrum to which the eye was directed; above and below, the blue was much brighter, and by moving the eye, the blue spot ran up and down the blue band of the spectrum as if confined in a groove. I found that none of the other colours became dark in the same way when looked at directly.

* At page 112 I have erroneously represented Dr Earle as having only seventeen colour-blind relatives.

" Last spring, Professor Forbes kindly allowed me the use of his apparatus for the purpose of repeating this observation. By using a telescope along with the prism, and so obtaining a large field of pure colour, I found that the dark spot could be best seen in the blue, and presented the appearance well known to be due to the yellow spot. It became fainter in the more refrangible rays, but was brightest in the line F, and on to G. Beween F and E, I think, it suddenly disappeared, reappearing as a light spot in the yellow and orange. I am not quite sure, however, that the latter effect was not produced by the former; for I could not attain it without looking first at the blue, and then suddenly at the yellow.

" The best way of seeing this is by means of a whirling disc, supported by an axis, so that it may be made to go slow for some time without stopping. By putting on this disc, sectors of ultramarine and chrome yellow in the proportion of 3 to 1, the effect of the change of the light entering the eye from yellow to blue might be observed by slowly turning the disc, so that each colour might be a sensible time before the eye, which was kept steady. Every time the blue came opposite, the dark spot appeared, and seemed to fade away gradually, if the yellow did not come in to relieve the eye from the effect of the blue. By properly adjusting the speed, the dark spot could be made to glimmer in a very conspicuous manner.

" The result shows that the yellow spot is *less* sensitive to *blue* rays than other parts of the retina. That it is *more* sensitive to *yellow* rays is less certain. A bright spot is seen when yellow succeeds blue, but I have not produced it by simply admitting yellow light."

Mr Maxwell intends to prosecute this inquiry.

NOTE F.

ON THE TRANSMISSION OF THE ACTINIC RAYS OF LIGHT BY THE HUMOURS OF THE EYE.

In connection with page 85.

Wartmann, in his *Deuxième Mémoire*, p. 40, states, that " the eye has the property of admitting only the luminous rays of the spectrum; it arrests the chemical radiations which accompany the more refrangible rays." In proof of this, he refers to experiments made with Guaiac resin, which, as first pointed out by Wollaston, becomes blue when freely exposed to the violet rays, but recovers its yellow colour under the red rays. This resin, however, if exposed to the more refrangible rays below the crystalline lens of an animal's eye, acquires only a light green colour, and changes to this if it have previously been rendered blue by direct exposure to the violet rays. This effect, Wartmann adds, is still more marked, if the cornea as well as the lens is made to transmit the light.

I have questioned the adequacy of these experiments, without detailing them (*note*, p. 85) to decide the question under consideration. Guaiac resin is not sufficiently sensitive to actinic influence to furnish a delicate

test of the transmissibility of the chemical rays of light by the humours of the eye. Only the daguerreotype-plate, or the highly-sensitive surface of collodionized glass, or calotype-paper, could determine the question.

As it was of interest, in relation to the Theory of Vision, to settle this point, I gladly availed myself last autumn of the offer of Mr Allan B. Dick and Mr John Spiller, both of the Metallurgical Laboratory, 28 Jermyn Street, London, to make the requisite trials. The former had been my laboratory pupil and assistant for several years, and was known to me as a skilful manipulator and very conscientious observer; the latter received the same character from my friend, Dr Percy, the Professor of Metallurgical Chemistry in the Jermyn Street School of Science, and has the reputation of being an experienced photographer. The collodionized glass plate with the rhombic image on it, and the negative pictures of the key, and of the window-curtain referred to in the succeeding statement, were sent to me, and fully coincide with what is related concerning them.

Experiments to determine whether the Chemical Rays are transmitted through the Humours of the Eye. By Messrs Dick and Spiller.

An ox-eye was prepared by cutting away the sclerotic until the choroid came into view; a circular aperture of one-eighth of an inch in diameter was then made through this membrane and the retina, which laid bare the vitreous humour at a point opposite to that where the light enters. The eye was then supported in the brass mounting of a photographic lens (*i. e.*, a brass tube adapted to the front of a camera) resting at the posterior end on a ring of cork which fitted tightly into the tube, and retained in front by a diaphragm, so as to permit the cornea to protrude. From the arrangement of the fittings, we are quite satisfied that no light, excepting that which passed through the eye, could enter the camera.

Within the dark box, a strip of black paper with a diamond-shaped or rhombic aperture occupying the greater part of its breadth, was extended across in front of the prepared collodion plate, so as to throw its image on the latter in the event of any chemical rays finding their way to it. The camera was then pointed to the sky (the morning being bright and the sun shining), and the plate exposed for fifteen seconds. On developing with solution of sulphate of iron, a very decided picture appeared. The glass plate which accompanies this paper was the result of twenty seconds' exposure.

The conclusion derived from this experiment, although perfectly satisfactory to those who arranged the apparatus, is open to the objection on the part of others, that the picture does not present any *prima facie* evidence of its being the result of rays which have passed through the eye. We therefore endeavoured to copy photographically the actual image which is depicted on the retina. To do so, another bullock's eye was carefully dissected, so as to open a circular space of about three-eighths of an inch in diameter at the back of the eye, the retina was removed, and a very thin film of glass, in shape like a watch-glass, substituted for it; this supported the vitreous humour in its original position, and served also to prevent its contact with the photographic paper placed behind to receive the impression. In another trial, the retina was left untouched, without altering the ultimate result.

Iodide of silver paper was then made sensitive to light by a wash of gallo-nitrate of silver, and used as in the talbotype process, small squares of the wet paper being successively applied to the back of the thin glass film and exposed for varying periods (one minute on an average) to the different objects to which the bullock's eye was presented. On developing the latent images with strong gallo-nitrate of silver, very distinct pictures were obtained of a key and of a spotted window-curtain. These negative pictures are enclosed. It is thus beyond a doubt that the chemical rays penetrate the humours of the eye and impinge upon the retina.

ALLAN B. DICK.

London, October 11, 1854. JOHN SPILLER.

NOTE G.

ON THE RELATION OF THE COLOUR OF THE CHOROID TO COLOUR-VISION; AND ON ALBINISM IN RELATION TO COLOUR-BLINDNESS.

In connection with pages 88-104.

The question discussed in the pages indicated above is in some respects treated more fully in the paper "*On the eye as a Camera Obscura*," Trans. R. S. E., vol. xxi., part ii., p. 327, in which the conclusions contained in the text are slightly modified, and greatly extended. The points in that paper most calling for notice, as affecting the statements made in reference to intra-ocular reflection throughout the whole discussion of the chromatic theory of colour-blindness (pp. 77-104), are the following:—

1. The existence of much reflection of light from the retina and choroid in the human eye has been established in the fullest way since eye-specula and opthalmoscopes have been multiplied and extensively employed.

2. The observations on the colour of the human choroid, and of the light reflected from it (pp. 98-100), which, in the text, are based chiefly upon examinations of the dead eye, can now be replaced by results obtained through examinations of the living eye. From these it appears that the light reflected from the human choroid is always red, yellowish-red or brownish-red. The term *pale*, frequently applied in the text to the surface of the choroid (p. 100), must be understood as referring to the *dead* eye, and as implying a small amount of pigmentum nigrum. The pale surface of the dead choroid, with its bloodvessels empty, is bright-red during life when these vessels are filled with blood.

3. A careful examination of human and animal albinoes has satisfied me that their vision, though sometimes exercised with discomfort, is optically as perfect as that of non-albinoes. They cannot see in light so bright as to dazzle them, but neither can the possessors of normal eyes, and in continuous light such as can be borne by them, albinoes see distinctly, although intra ocular reflection is at a maximum in their eyes. Instead, therefore, of their vision throwing a difficulty in the way of the conclusions urged in the text, which the statements of writers on albinism had led me to think it did, I am satisfied, from my own observations on

animal albinoes, and from the testimony of intelligent albinoes of our own race, that the reverse is the case. And if vision be compatible with the immense amount of internal reflection occurring in the albino eye, it can suffer no obstruction from the much smaller amount occurring in the normal eye, whether provided with a tapetum or not.

4. The suggestion in the text that the light returned through the retina from the choroid behind it is positively serviceable to vision, is likely to be more than confirmed by the recent microscopic investigations of the retina made on the continent and in this country. Professor Goodsir of Edinburgh, in particular, has made known a striking hypothesis according to which, vision is exercised *solely* by the light *returned* from the choroid.—*See P.S. to Memoir on the Eye as a Camera Obscura.*

So far as albinism is related to colour-blindness, I have mentioned in that memoir that an Albino girl, carefully examined by Mr James C. Maxwell and myself as to her sense of colour, was found to possess that sense in perfection, so that she adds another case to those already on record, as proving that Albinism and Colour-Blindness do not necessarily go together.

Since the publication of that case, I have received an account of the more marked features of his Albinism from a barrister in England, an experienced observer, and highly accomplished man. After stating that he generally uses the left eye in reading, and that he is very short-sighted, he continues, "The eye is clear and correct so far as it goes, and appreciates colour well." He also mentions that his eyes "are impatient of light; but though much inconvenienced by it, I do not think my vision is better in twilight or worse in sunlight." This fact is of great interest to myself, as vindicating the justice of the conclusion which I have urged, that the vision of Albinoes may be painful, but is not optically defective.

NOTE H.

ON THE PHRENOLOGICAL ORGAN OF COLOUR IN RELATION TO COLOUR-BLINDNESS.

In connection with pages 104–108.

In his important work just published, "Phrenology applied to Painting and Sculpture," Edinburgh, 1855, Mr George Combe has commented on the opinions I have expressed in the text adverse to the phrenological explanation of Colour-Blindness (see Appendix to his work, No. I., p. 146). With rare courtesy, Mr Combe allowed me to peruse his criticism in proof, and willingly altered it where my meaning had been misapprehended. As it now stands, I have to acknowledge the justice of his objection to the passage on page 108, which runs thus:—"It appears vain, therefore, to expect to discover the existence of Colour-Blindness by so rude an external indication *as the prominence* over a small area of one of the plates of the skull." If the reader will alter "*the prominence*" into "the *degree of* prominence," he will render my meaning distinct. The preceding context will show that I did not seek to attribute to phrenologists the opinion that a prominence in the superciliary ridge is the index of an *imperfect* sense of colour, but the reverse. The sentence, however, if taken alone,

seems to signify this, and, had I perceived its ambiguity, would have been altered.

This, however, is a secondary point. The main object of Mr Combe's strictures is to show that the only cases which afford *instantiæ crucis*, in reference to the phrenological explanation of Colour-Blindness, are those which present "a great and manifest depression" in the superciliary seat of the 'organ of Colour.' "A depression of this kind," says Mr Combe, "phrenologists affirm is *uniformly* accompanied by a greater or less degree of deficiency in the mental power of perceiving, discriminating, and remembering colours; not, however, in all cases amounting to Colour-Blindness," (*Op. cit.*, p. 146); and as the late Lord Jeffrey had been referred to by phrenologists, as possessing a feebly-developed organ of Colour, and was therefore a case in point, whilst his perception of colours was in many respects remarkable; I adduced his example (as he had done himself), as unfavourable to phrenology. Mr Combe now seeks to show, by additional evidence, that Lord Jeffrey had, in conformity with his depressed organ of Colour, a feeble sense of that quality of bodies.

As I regard Lord Jeffrey's case as affording in some respects an unexceptionable *instantia crucis*, I return here to its consideration, but not in a polemical spirit.

After adducing a letter from D. R. Hay, Esq., written in answer to a request of Mr Combe's, that he would give him his opinion on Lord Jeffrey's mental power in regard to colour, and containing the expression on the part of Mr Hay, that Lord Jeffrey "was defective in the power of comprehending and appreciating the natural principles of beauty in colouring," Mr Combe continues, "I rest the conclusion that Lord Jeffrey really had not a great power of appreciating colours on the fact that his delight was in brilliant colours, whereas individuals who enjoy great sensibility to tints, prefer rich and mellow colours finely harmonised; 2*dly*, on Mr Hay's testimony that he was unable to describe the colour he desired to have painted; and, 3*dly*, that he absolutely denied the existence of harmonic relations between colours, and showed practically that he was blind to them."

Now, whether Lord Jeffrey had a *fine* sense of the harmony of colours, is not a question I propose to discuss. No one is better entitled than Mr Hay to decide such a point, provided his means of testing it were sufficient. But they do not appear to have been; at least the reasons he assigns for the opinion given in the close of his letter are very inadequate; the majority of them being founded on negative observations, and those which are not, resting on statements which, in my judgment, warrant the very opposite conclusion of that he draws. I allude to them here, only in so far as they affect the determination of Lord Jeffrey's perception of colour as a simple phenomenon. His delight in brilliant colours is no proof that he could not distinguish sombre ones, for the two powers are found together in the great painters famous as colourists. If, indeed, it could be shown that he delighted *only* in bright colours, the argument might be worth something, but this is not shewn, and the opposite appears to have been the case; for by Mr Hay's account he preferred a very subdued colour for his dining-room walls. Nor can he be said not to have described this particular colour when he spoke of it, as Mr Hay says he did, "as something between the colour of an old parchment and an Etruscan vase." The

author of the "Nomenclature of Colours," who does not himself propose a name for the ambiguous colour, will, I am sure, not decline to acknowledge that such mixed tints are not easily defined, even by those who have made colour-nomenclature a special study, and that even educated amateurs have only a single vague term, such as buff, drab, or stone colour, to apply to them throughout many shades. Mr Hay's statement also, that Lord Jeffrey appeared, in fixing on the colour of the walls of his dining-room, to make little or no allowance for the influence of the drapery, furniture, and other accessories of the room, in affecting the tint of the walls, is at best a most uncertain conclusion. Lord Jeffrey's silence on these points is held to signify that he was indifferent to the contrast of colours, although it took the artists the greatest trouble to paint a wall so as to please him. His action here was surely as expressive as words could have been. Only recently Mr Hay himself, Field, Chevreul, and a few other authors, have accustomed us to remember in our house decorations, how much the quality of one colour is affected by its proximity to another. It is too much, surely, to expect that a private gentleman who had never handled colours, should be as much and as consciously alive as a skilful and experienced professional painter, to the effect of approximated tints in altering the appearance of each other: the great majority of educated men would still, I apprehend, if judged by their formal references to the subject, appear to be as indifferent as Lord Jeffrey to the modifications of colours induced by their juxtaposition. If he was indifferent, why was he so fastidious? I cannot indeed avoid asking Mr Combe and Mr Hay if it is not singularly at variance with their conclusions, that a person *ex hypothesi* so deficient in appreciation of colour as Lord Jeffrey, should so pertinaciously insist upon a particular subdued tint, and no other, being applied to his walls. One would have expected him, according to Mr Combe's view of his case, to have chosen some brilliant colour, and to have been by no means nice as to its exact tint or shade.

Nor am I at all satisfied that Mr Combe is justified in his conclusion, that Lord Jeffrey was blind to the existence of harmonic relations between colours. His denial that such relations existed, is at least no proof that he was not alive to them. Mr Ruskin denies the complementary harmony of colours, and yet shows by his writings that he fully appreciates it. Lord Jeffrey's Association-theory of Beauty led him to attribute to anything rather than a native power of perception, the pleasure which contrasted sights or sounds gave him; but most certainly (as the dining-room wall illustrates) all colours did not equally please him, and the question of real importance, but on which we have no evidence, is, what were the contrasts of colour which gave him pleasure, not how did he account for that pleasure.

But I shall be content to urge that Lord Jeffrey's perception of single colours was perfect. On this point there is no room for doubt. Mr Hay states, in his letter to Mr Combe, that "In respect to single colours Lord Jeffrey was peculiarly fastidious in his choice;" and in the text of this work I have referred to his recorded delight in looking at brilliant colours, and his rare power of matching colours from memory. He was thus the very reverse of colour-blind, and yet he had the phrenological index of Colour-blindness. The organ of Colour was to a great extent wanting in him, and yet he possessed the power of distinguishing

colours in great perfection. Even if it be conceded, as for argument's sake I will concede, that he had no sense of the harmonious relations of colour, still, to use Mr Combe's own words, he exhibited no "deficiency in the mental power of perceiving, discriminating, and remembering colours." If then the depression, *i. e.* the more or less entire removal, of the organ of Colour does not induce colour-blindness, with what reason can it be argued that where the absence of that organ *coincides* with the presence of colour-blindness, the absence of the one is the cause of the presence of the other? A single case of the undeveloped organ, without the developed colour-blindness, is as fatal to the doctrine, that they stand to each other in the relation of cause and effect, as the presence of perfect vision in the absence of the eye would be to the belief that blindness necessarily results from the loss of that organ.

I have dwelt at length upon Lord Jeffrey's case, because it appears to me unexceptionable, as a test of the relation of colour-blindness to the phrenological organ of Colour; and to be unaffected by the decision either way of the question, Had he a keen sense of Chromatic Harmony? But I will go further. Not only is it the fact that there are many persons (whatever may have been the case with Lord Jeffrey) in whom the power of distinguishing colours is largely manifested, without any corresponding power of recognizing their harmonious relations; but the opposite is also to a great extent true, although it has not attracted equal attention. It is of course impossible for one who cannot perceive colours, to perceive their harmonious or inharmonious contrasts; but many of the colour-blind, although they err flagrantly in the discrimination of certain colours, *appear* to exhibit a delight in watching the contrasts of those which they can discriminate. I say "appear," for I would not speak too confidently on a subject which the absence of a common language between the colour-blind and the colour-seeing makes it difficult to submit to accurate analysis. But the considerable number of professional and amateur artists included in my list of colour-blind acquaintances, and the mode in which they discuss paintings, lead me to suspect that they have a perception of colour-harmony greater than their perception of colour. I was long disposed to impute the pleasure which they received from coloured works of art, to the recognition simply of the graces of form, and outline, and the effects of light and shade in such pictures. But they do not judge their own cases thus, as the language of Mr R. the engraver (p. 27) and Mr N. (p. 29) will illustrate; and Dr E. (p. 21) claims to receive as much delight from Etty's gorgeous colouring as others do.

If, moreover, a preference of subdued to brilliant colours is a sign of a highly-developed sense of colour (as phrenologists affirm), colour-blind artists may claim to possess such a sense, for they work by choice with greys and neutral tints. On this, however, I do not insist; but the possibility of a sense of colour-harmony co-existing with a defective perception of colour is illustrated by the case of Mr B. (p. 39), who was rendered colour-blind by a cerebral injury, and now perceives only bright yellow and blue. His perception of colour-harmony remains notwithstanding, and is now a cause of distress, by rendering him alive to the absence of those chromatic relations in coloured objects which his æsthetic sense craves. He is like Beethoven after he became deaf, when he could still conceive and compose the most complex musical harmonies, although he

was unable to detect the false notes of his piano, or the unintended discords of his orchestra. When it is remembered that yellow, blue, white, and black are visible, when fully illuminated, to most of the colour-blind, and that red in favourable circumstances is also visible, it will be apparent that there is ample room within the circle of these colours for the manifestation of a sense of colour-harmony. And, accordingly, the colour-blind do not exhibit indifference to the pleasing and displeasing contrasts of colours, to the extent of their colour-blindness. To some of them colour is æsthetically a *negative quantity*, a source neither of pleasure nor pain. To others again, within the compass of their chromatic vision, colours are an object of delight, and their contrasts are to some extent perceived. My friend Dr E., for example, and I had admired flowers together for years without my discovering his colour-blindness. Mr N. (p. 29) states that "it is quite an *enjoyment*" to him to look at crimson flowers by candle-light. Prof. Y. (p. 32) has always "*delighted* in going into a conservatory by candle-light, because then all the purple and red flowers stood out in such brilliant *contrast* to the green leaves." Mr T., although liable to mistake red for black, is "fond" of scarlet and crimson, and at the distance of a few feet can see them well enough (p. 30); and Lady D. states that "the colours of nature abound in richness to her senses" (p. 37.)

I would commend (and in no captious spirit) these cases to the consideration of phrenologists. Conceding, for the time, that there are such cerebral organs as they suppose, the cases adduced appear to render most improbable the theory that *one* such organ is alike the instrument of the recognition of colour as a simple phenomenon, and of the contrasts, harmonious and inharmonious, of colours judged æsthetically. To refer, therefore, as Mr Combe does, to colour-blindness, as if it were the extreme or worst result of absence of the organ of Colour, and to a defective sense of colour-harmony as a slighter manifestation of the same affection of vision, is to employ the language of a hypothesis which our experience shows cannot be true, however true it *may* be that there is a portion of the brain specially related to the perception of colour.

The question is one of interest to psychologists of every school. They have long recognised that a sensuously acute "hearing ear" and an æsthetically sensitive "musical ear" are two different things, seldom possessed in equal degree, and that the former is a greatly more common endowment than the latter.

The eye is similarly circumstanced, and many of the totally blind must possess in a dormant, yet it may be not altogether inactive condition, the sense of colour-harmony. Locke's famous blind man, who likened scarlet to the sound of a trumpet, was possibly employing this sense when he made his strange comparison, at which we should perhaps wonder rather than smile.

The recognition of colours in themselves is a comparatively simple intellectual act, which probably many of the lower animals can perform as readily and perfectly as ourselves. Children, especially girls, distinguish colours with a celerity and certainty which no adult can surpass; but in their doll-dressings and other chromatic devices, they show little relish for harmonious colouring, and delight chiefly in gaudy tints. It is not, I believe, till adolescence is passing into manhood or womanhood that the power of apprehending colour-harmony shows itself with

any force; and thereafter it requires and rewards cultivation to a far greater degree than the simple recognition of colours does. I cannot, accordingly, understand how phrenologists acknowledge two organs (*Time* and *Tune*) in reference to the ear, and only one in reference to the eye; but it is for them to settle this question. The facts of colour-blindness appear to me to render incredible the accepted phrenological doctrine of colour.

NOTE I.

ON RED-AND-GREEN SPECTACLES AS PALLIATIVES FOR COLOUR-BLINDNESS.

In connection with pages 115, 116.

At page 116 I have expressed an unfavourable opinion in reference to the value of red *or* green spectacles as a means of enabling the colour-blind to distinguish red objects from green ones. Mr James C. Maxwell, however, has proposed the employment of red *and* green glass *simultaneously*, in a mode which is free from the objections raised in the text against the use of either singly. A spectacle frame of the usual kind is constructed with one glass *red* and the other *green*, so that the right eye, for example, of the wearer of the spectacles looks always through red, and the left always through green. Through the red glass red objects appear *brighter* than green ones; through the green glass green objects appear brighter than red ones, so that a colour-blind person puzzled between red and green has only to determine whether the doubtful colour appears brighter to the right or the left eye, and to set it down as of the colour of the glass which brightens it. The spectacles must, of course, have a single bridge, so that the same glass shall always be opposite the same eye, and the colour-blind party using them must know from independent authority which of the eye-pieces is red and which green.

Mr Maxwell's description of this ingenious device is contained in his paper "*On Colour, as perceived by the Eye, with Remarks on Colour-Blindness.*" Trans. R. S. E. for 1854–55, vol. xxi., part ii.

The red-and-green spectacles are at present on trial by colour-blind parties, and the results will in due time be made known by Mr Maxwell.

NOTE J.

ON A PECULIARITY OF EXPRESSION IN THE EYES OF CERTAIN OF THE COLOUR-BLIND.

In connection with page 152.

Since the passage in the close of the Supplement, referring to a peculiar expression in the eyes of certain of the colour-blind, was written, I have had the opportunity of observing it somewhat particularly in four gentlemen not relatives, in two of whom it was readily recognised by others. All the parties referred to have healthy eyes, and excellent vision for everything but colour. One has an absent, anxious glance,

with something of the expression which amaurosis gives, only the pupil is small. One has a startled, restless look. The other two have an eager, prying, aimless air. The character common to them all, and to the other cases I have seen, is this aimlessness of look. Macbeth's reference to Banquo's ghost—

> "Thou hast no speculation in those eyes
> Which thou dost glare with"—

very happily expresses the peculiarity which I find it so difficult to define. It has not, however, in most cases anything repulsive about it. The majority of those I have seen presenting it would be described as having fine eyes. In one the wistful, somewhat melancholy, but pleasing expression of his eye had attracted my attention long before I knew that he was colour-blind.

I do not know whether Dalton or the other famous examples of colour-blindness had any such look as I have referred to. This note may lead others to make further inquiry on the matter.

NOTE K.

ON THE THEORY OF THREE PRIMARY COLOURS, AND OF THREE ELEMENTARY COLOUR-SENSATIONS.

In connection with pages 153-159.

Throughout the Researches and Supplement I have employed the current language in reference to colours, which represents white light as the sum of so much red, yellow, and blue light, and the colours of natural and artificial objects as depending on the extent to which they send to the simply recipient eye more or less of one or other of these three kinds of light. This is the only theory of colours, and of their perception, sufficiently popular to be employed in the discussion of colour-blindness before general readers. But since this work was commenced the whole question of colour as a product of light, and an object of sensuous perception, has been discussed by men of great genius and aptitude for physical research, and the general tendency of their conclusions has been adverse in some respects to the popular theory of colours, whilst the phenomena of colour-blindness have been appealed to alike by the advocates and the assailants of that theory as justifying their view.

The great majority of practical questions connected with colour-blindness will not be affected, so far as their exposition and discussion are concerned, by the adoption of one of these views rather than the other. It is otherwise, however, with the problem of the origin or physical cause of colour-blindness; and as our means of palliating or remedying this must largely depend upon our conception of its essential nature, it cannot be immaterial from what point of view we regard it. The very beautiful and ingenious researches of Mr Maxwell, first announced in abstract in the communication on page 153, and since published in full in the Transactions of the Royal Society of Edinburgh, (vol. xxi., part ii., p. 275), have originated in a theory of colour adverse to the prevalent one, but which, in the hands of its advocate, has led to the invention of

the colour-top, and to the device of red-and-green spectacles, which promise materially to serve the colour-blind. After all, however, even the theory of colour-blindness is less affected in its mode of statement by the particular view we adopt of the nature of light as judged by the eye, than at first sight might be expected. This will appear from what follows.

In our ordinary discussions on colour we assume deliberately or tacitly that the hypothetical optical and the actual sensational analysis of light must of necessity yield the same result. We suppose the colours we see to be intrinsically such as we see them. What the eye pronounces to be red was red before it reached the eye; it has only recognised the redness, which exists the same whether recognised or not. This assumption plainly does not admit of proof. So far as optical analysis is concerned, it appears that, according to some, white solar light can be resolved into seven coloured beams, such as Newton is popularly assumed to have acknowledged. According to others these seven may be further analysed into three, which, following one party, are red, blue, and yellow; and, following another, are red, green, and violet. According to others still, the number of perfectly distinct kinds of coloured light in white light is countless.

This last is the only opinion worth holding when our object is to compare the hypothetical optical with the actual sensational analysis of light; for on every other view our reasoning proceeds in a vicious circle: we only compare sensations with sensations.

Assuming, then, that the kinds of coloured light are infinite in number, we inquire, To what extent does the eye acknowledge this infinity? This problem is plainly to a great extent within our reach, as we can ascertain by direct trial how many colours we can distinguish from each other, and how many we can produce by the mixture of others; the mixture of coloured lights being preferable in such trials to the mixture of pigments.

Observations made in this way by Newton, Young, Herschel, Brewster, Helmholtz, Maxwell, and others, have led to the conclusion that for the normal eye there are three primary sensations of colour; none of these can be produced by the others, either singly or united, but every other colour-sensation is the result of two or all of these sensations being experienced together, in greater or less relative quantity, intensity, and purity. There is thus a common consent as to the existence of three elementary colour-sensations: more than three cannot be conceded, for all colour-sensations but three can be referred to these: and fewer will not suffice to account for all the colours we perceive.

There is not the same agreement as to what the three elementary colour-sensations are. Newton (but this is doubtful), Herschel, and Brewster, besides many more, have regarded red, yellow, and blue as the three sensational colour-elements; and mankind in general have long considered this conclusion as established beyond question by the universal and successful practice of workers in colours, who produce all the tints and hues they desire from mixtures of red, yellow, and blue, along with white and black. But recent experiments in the hands of J. D.

Forbes, Helmholtz, Maxwell, and others, have brought out the very unexpected result that although yellow and blue mixed in one way produce green, mixed in another way they produce pink; and this result, as well as others, has led some observers, following in this respect Young, to deny to yellow and blue the character of primary colour-sensations, and to replace them by green and violet; whilst, as Mr Maxwell has very forcibly illustrated, any three colours may be regarded as primary, provided by their union they constitute white light. The phenomena of colour-blindness, nevertheless, assign to red a specialty and prominence among colours which warrant its being made a primary, and it is the only colour which all opticians are willing to consider such. If, however, red be retained as one of the chromatic primaries, the other two need not differ much from yellow on the one hand, and blue on the other. Mr Maxwell, accordingly, whilst declining to speak definitely on the non-red primaries, in the absence of any method of determining their nature, observes that "one must correspond to blue, and the other to a green verging to yellow."—P. 158. (See also *Trans. R.S.E.*, vol. xxi., p. 287).

There is thus comparatively little difference introduced in the language employed to describe the features of colour-blindness, by altering two only of the primary colour-sensations. If all three, however, were altered, as it is quite competent for any theorist to alter them, provided those he substitutes produce by their union in certain proportions white light, then the language applicable to normal and abnormal colour-vision would demand a corresponding alteration. But the phenomena of colour-blindness furnish so strong an argument for regarding red as one of the primary sensational colours, that it is likely to keep its place as such whatever alteration be made on the other two; and as the one of these will have much blue, and the other much yellow in it, we may, without introducing any material error, call them simply blue and yellow, especially as these, along with red (including white and black), can be made to yield all the colours of the painter, dyer, or pigment-maker. Accepting these terms, then, we may say that the normal eye reduces its colour-sensations to three, and analyses white light into three coloured elements, one of which is red; and that the colour-blind eye, on the other hand, reduces its colour-sensations to two, and analyses white light into two elements, neither of which is *red;* for colour-blindness takes its character more from its non-recognition of red than its positive recognition of blue and yellow, (or of the other two primaries whatever they are), and might with some propriety be called *An-erythric* (No-red) vision.

The essential distinction which can thus be drawn between perfect normal colour-vision and fully-developed colour-blindness, has not till recently been distinctly recognised. Young's hypothesis of a threefold retinal or cerebro-nervous arrangement of the normal eye, each portion of which is the organ of one of the three primary colour-sensations, prepared the way for the doctrine discussed above. This doctrine was also stated with the greatest clearness in Sir J. Herschel's letter to Dalton, quoted at p. 60; but, though written in 1832, this letter has only become known to others than its first receiver since its publication by Dr Henry, in his Life of Dalton, p. 25. To Herschel we are indebted for

the term *Dichromic* (cognizant only of two colours), which most happily characterizes the colour-blind.*

The importance of this distinction was brought strongly under my notice, before reading Herschel's letter to Dalton, by the discovery of those singular examples of total blindness to red which are detailed in the text of these Researches, but had not previously attracted attention. These examples could not be studied or described, so far as their mere phenomena were concerned, and apart from all theory (except that red is a primary colour), without betraying their dichromic character. —(*Researches*, pp. 53-67).

The same character was again brought before me in discussing the phrenological explanation of colour-blindness, and led me to urge that, even if that explanation were well founded, a third only of the hypothetical organ of Colour, that, namely, which is related to the vision of red, should be wanting in the colour-blind.—(*Researches*, pp. 107-108).

And, lastly, when, putting all theories aside, I busied myself with the purely practical question of providing three colour-signals for use on railways, I was again compelled to notice, not only that the three primary colours of popular theory could not be distinguished from each other by colour blind signal-men, but that there were no three colours, primary (on any theory), secondary, or more composite, which could be distinguished from each other by them.—(*Supplement*, pp. 128 and 136). It was thus shown to be a simple fact that normal vision is *trichromic*, and colour-blind vision *dichromic*.

It is to Mr Maxwell, however, that we are indebted for the fullest exposition of the twofold nature of colour-sensation in the colour-blind, as distinguished from its threefold nature in the normal-eyed. His researches were carried on independently of mine, and in a different way. They have led him to conclusions similar to mine on the subject discussed in this work, but also to many novel and important results, which are all his own. He has carried the inquiry much further than any one else, and by his simple, but very ingenious and satisfactory mode of experimenting with the colour-top, has, for the first time, given *quantitative* analyses of normal as contrasted with colour-blind vision.

The language, then, of the popular theory of primary colours employed in the text of these Researches cannot introduce any error of consequence into the discussion with which they are occupied; but I would qualify the statements with which this note is chiefly occupied by two remarks.

1*st*, It is only in fully-developed colour-blindness that vision is decidedly dichromic, and even then it is not absolutely so, at least so far as my experience goes. I have not found any colour-blind person utterly devoid of the power of recognising red. Even those to whom it was frequently invisible, and appeared black, could at

* Unfortunately Wartmann has rendered Herschel's term less significant by his previous (published) use of "Dichromatic" in connection with Daltonism, to indicate that rare form of it characterized by the perception only of *white* and *black*, in contradistinction to "Polychromatic" Daltonism, where various colours are perceived and many mistaken.

times perceive it to be different from all other colours, and named it red.

2d, It appears to me to be an interesting feature of colour-blindness, which other writers on the subject do not acknowledge, that those who suffer from it are liable to mistake the light tints of *all* colours for each other, and the dark tints of *all* colours for each other. I have dwelt upon this repeatedly in the text of these Researches, and refer to it here simply to remind the reader that, if my observations are well founded, the vision of the colour-blind is not merely dichromic in reference to full colours, but, in the case of *tints* and *shades*, tends to become *achromic*, or altogether non-perceptive of colour.*

NOTE L.

ON COMPLEMENTARY COLOURS AS PERCEIVED BY THE COLOUR-BLIND.

In continuation of last Note.

To analyse light is not the only function of the normal eye. It can effect the synthesis of its elements also, and is constantly doing so, and the difference between normal and colour-blind vision is as marked in the performance of this synthesis as in that of the analysis discussed in the preceding note.

As all colours are resolved by the perfect eye into three, so the power of adding to any colour presented to it the other colour or colours which along with it constitute white light, is equally its prerogative. In this synthesis light is not treated as made up sensationally of three coloured elements, but of two. Of these one is necessarily compound, and the other is either simple or compound, according as the one-half of the colour-elements is a primary colour, such as red, or a secondary colour, such as purple.

The colours which thus *complete* by their union white light, have long been distinguished as *complementary*. The laws regulating their perception have been more or less studied from an early time, and all the great writers on Optics have dwelt upon them.

It is to Chevreul, the French chemist, however, that we are indebted for the fullest study of complementary colours in their phenomenal relations, and as objects of perception to the eye. (See his Work on *Colour*, *passim*). His predecessors had shown that, when the eye gazes long on any colour, it sees, if directed thereafter towards a white ground, the complementary colour, and (as Chevreul specially illustrates) if turned to a new colour, it sees that tinged by the complement of the first. He has farther shown that, side by side with the visual perception of any colour, there arises, without the exercise of long gazing, the impression of its complement. This latter experience he refers to as the "simultaneous contrast of colours," the former as the "successive contrast." Many

* If Young's colours, red, green, and violet, were taken as primary, then colour-blind vision could not be called dichromic, for all those colours are in whole or in part invisible or uncertain to it. If the green, however, were a yellow-green it would appear yellow to the colour-blind, and the violet, whatever its shade, would appear blue.

visual phenomena result from the combined result of these twofold experiences.

There is thus, as it were, a continual effort on the part of the normal eye to produce for itself white light out of its coloured halves. It acts as if dissatisfied with the moiety offered to it, and adds of itself the missing remainder.

It is not necessary to enter into the psychological or physiological explanations of this visual act. I will only remark here of it that it appears to be a true example of a polar manifestation of force, understanding by polarity the exhibition, in two opposite directions or modes, of one force, which undergoes a twofold division, but into inseparable halves, so that unity co-exists with division. Thus magnetism displays itself as the so-called northern magnetism and southern magnetism, which always go together, and cannot exist apart, so that the production of a magnet with only a north or a south pole is impossible. Electricity always shows itself as positive and negative electricity, neither being producible without the other.

Now, as the production of a north pole in a bar of magnetised iron infers and necessitates the development of a south pole, and as the induction of a positive electric pole cannot take place without the induction of a negative electric pole, so it appears that if we develop one-half of the full colour-sensation on the retina, it instantly adds the other half. This is seen best in Chevreul's "Simultaneous Contrast" of colours. Red is no sooner shown to the eye, than its complement green rises to view along with it. Yellow cannot show itself alone, but only as bordered with purple. Blue is inseparably accompanied by orange. If composite colours are presented to the eye, composite colours accompany them, but always according to the law, that the two sets of colours added together produce white light. In short, whatever colour we show to the normal eye, it infallibly countermatches it; and all that we ever do is to furnish the one half of white light, whilst the eye furnishes the other.

This, I think, is a true though unrecognised manifestation of polarity; but whether or not it be, there is no question that the vision of every colour, simple or compound, by the normal eye, is accompanied and followed by the perception of another and unlike colour, the recognition of which is matter of simple observation, apart from all theory.

For the colour-blind eye there are no such experiences, nor can there be. Purple, for example, appears as blue to it; orange shows as yellow, or red, or green; red and green are identical. In the case of the last two colours, indeed, it seems in many cases as if the colour-blind eye only exaggerated the action of the normal eye, and saw the complementary colour so quickly and vividly that it could not distinguish it from the primary. There has been a disposition accordingly on the part of some writers on colour-blindness, to regard it as always consisting in a tendency to mistake a colour for its complementary; but the absence of any liability on the part of the colour-blind to confound yellow with purple, or blue with orange, shows the necessity of limiting this theory. And in the case of red and green, there can be no question that the green apparently visible to the colour-blind eye when red is actually shown to it, is not the shade of green which to a normal eye would be the complement

of that red, but is much duskier and darker; and from red frequently appearing positively black to the colour-blind, we can only infer that *no* colour, primary or complementary, is seen. Although, therefore, it may justly be urged, that on certain occasions a colour-blind eye, in its perceptions of red or green, sees each unceasingly alternate with the other, and thus loses the power of distinguishing which is the primary and which the complementary colour; so that the abnormal eye might be compared to a magnet of which the poles are continually being reversed (as in certain electro-magnetic machines), whilst the normal eye, in its perception of a colour and its complementary, is like a compass needle, with one end permanently a north pole, and the other permanently a south pole; still the comparison only applies to those cases where the colour-blind eye distinguishes red from green, and exercises to some extent trichromic vision.

Observations have been made by Sir J. Herschel, Wartmann, and others, on the appearance of colours and their complements, as produced by polarized light, to the colour-blind. From these it appears, as might be anticipated, that the complements no more than the primaries showed to colour-blind as they do to normal eyes; but no general law has been deduced from these observations. Professor Kelland (whose important observations on colour-blind complementary vision are given at p. 109) tried along with me the effect of exposing the eyes of four colour-blind persons to an intense yellow soda-flame, lighted in a dark room, and then suddenly transferring them to a room lighted by the sun, where they were requested to gaze on white paper. It had a distinctly lilac tinge to our eyes, which like theirs had been directed towards the yellow light, but they saw no purple or any tint to distinguish the sheet from ordinary paper.

Experiments of this kind deserve repetition. Now that we know the comparatively simple dichromic character of fully-developed colour-blindness, we cannot doubt that those perceptions of colour which in the colour-blind correspond to the successive and simultaneous contrasts of colours so familiar to normal eyes must occur according to some simple law. If some of the subjects of well-defined (dichromic) colour-blindness would repeat Chevreul's experiments as he describes them, they might furnish us with important data for the extension of our knowledge of colour-vision. At present we must be content to speak negatively on the whole subject of complementary colours, as perceivable by those whose vision is dichromic. This, however, is quite certain, that the colour-blind eye cannot rival the normal eye in its power of uniting any more than in that of separating the elements of white light.



Note on inside of
front cover right p. 135
Brewin & Dove on Red Cap Ale — 64-65.
Done translated by Fyvie
Chief Mag Oct 1857 p 24

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